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DEVELOPMENT OF MATERIAL PROPERTIES FOR SLURRY INFILTRATED FIBER CONCRETE (SIFCON) — FLEXURAL STRENGTH

R. Mondragon

New Mexico Engineering Research Institute
University of New Mexico
Albuquerque, NM 87131

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Final Report

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Susan M. Cheney

SUSAN M. CHENEY
Captain, USAF
Project Officer

FOR THE COMMANDER

Thomas A. Bretz

THOMAS A. BRETZ, JR
Lt Col, USAF
Chief, Applications Branch

Carl L. Davidson

CARL L. DAVIDSON
Colonel, USAF
Chief, Civil Engrg Rsch Division

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This report documents the development of flexural strength material properties for slurry infiltrated fiber concrete (SIFCON). Included in this report are the procedures used, the material properties data base, all test results, relationship plots, and general conclusions.

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TABLES

METRIC CONVERSION TABLE

To convert from	To	Multiply by
Fahrenheit (°F)	Celsius (°C)	5/9 (°F - 32)
inch (in)	millimeter (mm)	25.4
foot (ft)	meter (m)	0.3048
pound/square inch (lb/in^2, psi)	kilopascal (kPa)	6.895
kips/square inch (k/in^2, ksi)	megapascal (MPa)	6.895
ounce (oz)	kilogram (kg)	0.02835
pound (lb)	kilogram (kg)	0.45
ounce (oz)	cubic centimeters (cm^3)	29.57
gallon (gal)	cubic meters (m^3)	0.00379

I. INTRODUCTION

OBJECTIVE

The objective of this subtask was the development of flexural material properties for slurry infiltrated fiber concrete (SIFCON). Included in this report are the procedures used, the material properties data base, all test results, relationship plots, and general conclusions. Methods for testing SIFCON in shear and tension were also investigated.

SIFCON DESCRIPTION

Slurry Infiltrated Fiber CONcrete, designated SIFCON, is a new composite material utilizing steel fibers in a cement-based matrix. It differs from conventional fiber-reinforced concrete in which the steel fibers are added to a typical concrete mix in a ratio of 0.5 to 1.5 percent by volume. SIFCON, on the other hand, starts with a bed of preplaced steel fibers in the range of 5 to 22 percent by volume. The fiber bed is then infiltrated with a low-viscosity cementitious slurry. The resulting composite material possesses very hign strength as well as ductility. In addition it has been demonstrated that SIFCON is highly resistant to dynamic loads such as blast pressure and ballistic penetration.

BACKGROUND

NMERI has been using SIFCON in various applications since 1983. In 1985 a SIFCON material properties development program was begun by AFWL/NMERI. The initial program was devoted to studying some SIFCON material properties in compression (Ref. 1). The program documented in this report is an outgrowth and expansion of the 1985 program. The 1985 program is referred to in this report as the "previous program" as distinct from "this program."

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1. Mondragon, Ray, **Development of Material Properties for Slurry-Infiltrated Fiber Concrete (SIFCON) - Compressive Strength**, AFWL-TR-86-43, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, December 1985.

SCOPE

This research effort focused on a study of SIFCON material properties in flexure. Four study groups investigated the effects of four major variables on the flexural strength. The effects on the flexural strength of varying the water to cement plus fly ash ratio, the fly ash to cement proportion, different fiber types, and different types and proportions of fine-grained sand were the focus of these four study groups. Five other study groups examined test methods to determine the reliability of the test results. These study groups included: (1) a method for testing composite beams, (2) the applicability to SIFCON of a standard test method used to determine flexural strength for conventional fiber concretes, (3) the edge effects of specimens on compressive strength results, (4) a method of testing SIFCON in shear, and (5) a method of testing SIFCON in tension.

Specimens were prepared using many of the same mix designs as in the previous research program. Both compression and flexural specimens were prepared, and both specimens were tested on the same day. The compression specimens served to produce a correlation between this program and the previous program, whereas the flexural specimens were tested to determine flexural material properties. All SIFCON specimens were tested at 30 days. Slurry cubes were also produced and tested at 7 and 30 days.

REPORT PLAN

Section II of this report includes a detailed description of the various procedures used in this test program. Section III includes not only a discussion of the detailed test results, but also explanations or interpretations of these results. From the detailed test results, several general conclusions about SIFCON material properties can be drawn. These conclusions are presented in Section IV. A major portion of this report is composed of Appendixes A through L.

II. PROGRAM PROCEDURES

GENERAL

Since SIFCON is a new and unique construction material, no standardized procedures exist for its production or testing. Most standards used for conventional concretes are not applicable for SIFCON; therefore many procedures used in this test program are unique.

FABRICATION PROCEDURES

The production of the SIFCON data base initially required the development of fabrication procedures. These procedures were formulated before any specimens were prepared so that consistency could be achieved throughout the program. A detailed step-by-step procedural checklist was developed for the laboratory technicians. This checklist also served as a data sheet for recording laboratory data and test results. Appendix L contains a copy of a sample checklist/data sheet used for each mix produced. Any deviations from the established procedures were noted on these data sheets.

The procedures used in fabrication and testing of the compression specimens were the same as those of the previous program with one exception discussed later in this report. The specific procedures used in the fabrication of flexure, shear, tension and other specimens are described in detail in the following discussion.

Table L1 in Appendix L contains a tabulation of general data related to the program. This table documents such data as personnel involved in the project, general mix information, and descriptions of the major equipment used. The following paragraphs present a description and rationale for each of the specific procedures used in this program.

TEMPERATURE CONTROL WET ROOM

Due to the renovation of the Civil Engineering Research Facility (CERF) at Kirtland Air Force Base, access to the wet room for curing the specimens was restricted. There was also a need for a room to control temperatures of

ingredients, molds, and specimens. Therefore a Temperature Control Wet Room (TCW room) was constructed for the first research program to accomplish both requirements. However, since the room was too small to also include the slurry mixer, it was expanded to accomplish this for this present program. Temperature was controlled with an air conditioner and heating system controlled by a thermostat. Wet curing of specimens was accomplished by submerging the samples in water in covered curing tanks placed in the TCW room. During the program, the average room temperature in general was maintained at 70 ± 2 °F. Refer to Tables J1 and J2 in Appendix J for a detailed listing of the temperatures recorded inside the room.

MIX INGREDIENTS

The mix ingredients used in this program are listed in Table L1. No deviations from these ingredients or the listed manufacturers were made. The cement and fly ash were in bagged form. The superplasticizer came in 55-gal drums. A list of the various fibers used and their properties and manufacturers is presented in Table 1. The fiber types used included five Dramix, four Xorex, and one Fibercon. The column in the table designated "SIFCON loading" is a calculation of the percent by volume of steel fibers contained in the SIFCON. These calculations were determined using the SIFCON slab molds and using the procedures described in the following subsection. Except for Study Groups 5 and 6 comparing various fiber types and edge effects, Dramix ZL 30/50 was the fiber used in all the mixes. Fine-grained sands were also tested as a SIFCON ingredient. Local, commercially available sands were used as identified in Table L1. Two masonry sands, designated by the supplier as plaster and brick sands, and three grades of blasting sands (fine, medium, and coarse) were studied.

PREPARATION FOR SPECIMEN MOLDING

All specimen ingredients, molds, tools, scale, and mixer were stored in the TCW room so temperatures could be controlled. Ingredients were placed in the TCW room a minimum of 3 days before use. The reusable steel molds shown in Figure 1 were used for all SIFCON specimens. The molds were lightly oiled for ease in stripping. SIFCON molds were also caulked to prevent leakage.

TABLE 1. FIBER PROPERTIES

Fiber type	Length, mm (in)	Equivalent diameter, mm (in)	Aspect ratio, L/D	[a]Tensile yield strength, MPa (kips/in^2)	SIFCON loading, percent		Manufacturer
					[d]This program	Previous program	
Dramix							
ZL 30/50	30 (1.18)	0.5 (0.020)	60	1170 (170)	9.6	11.6	Bekaert Steel Wire Corp.
ZL 50/50	50 (1.97)	0.5 (0.020)	100	1170 (170)	5.8	6.1	
ZL 60/80	60 (2.36)	0.8 (0.032)	75	1170 (170)	7.7	8.5	
ZL 30/40	30 (1.18)	0.4 (0.016)	75	1170 (170)	8.0	8.9	
OL 20/25	20 (0.79)	0.25(0.010)	80	2070 (300)	6.9	7.9	
Xorex							
I/1-in	25.4 (1)	[b]0.76-1.27 (0.03-0.05)	33-20	970 (140)	18.9	18.5	Ribbon Technology Corp. (Rib Tec)
I/2 1/2-in	63.5 (2.5)	0.76-1.27 (0.03-0.05)	83-50	970 (140)	5.8	10.1	
II/1-in	25.4 (1)	0.89(0.035)	29	(150-200)	21.4	22.5	
II/2 1/2-in	63.5 (2.5)	0.89(0.035)	71	(150-200)	---	9.8	
II/1 1/2-in	38.1 (1.5)	0.84(0.035)	43	(150-200)	13.5	---	
Fibercon 1-in	25 (1)	[c]0.43 [c](0.01675)	60	345-690(50-100)	6.9	8.4	Mitchell Fibercon Inc.

[a]As reported in manufacturer's literature.

[b]The range in values is due to the irregular shape of these fibers. They are neither rectangular nor circular in cross section.

[c]Rectangular cross section.

[d]The discrepancy in the percentages is explained in Study Group 7.

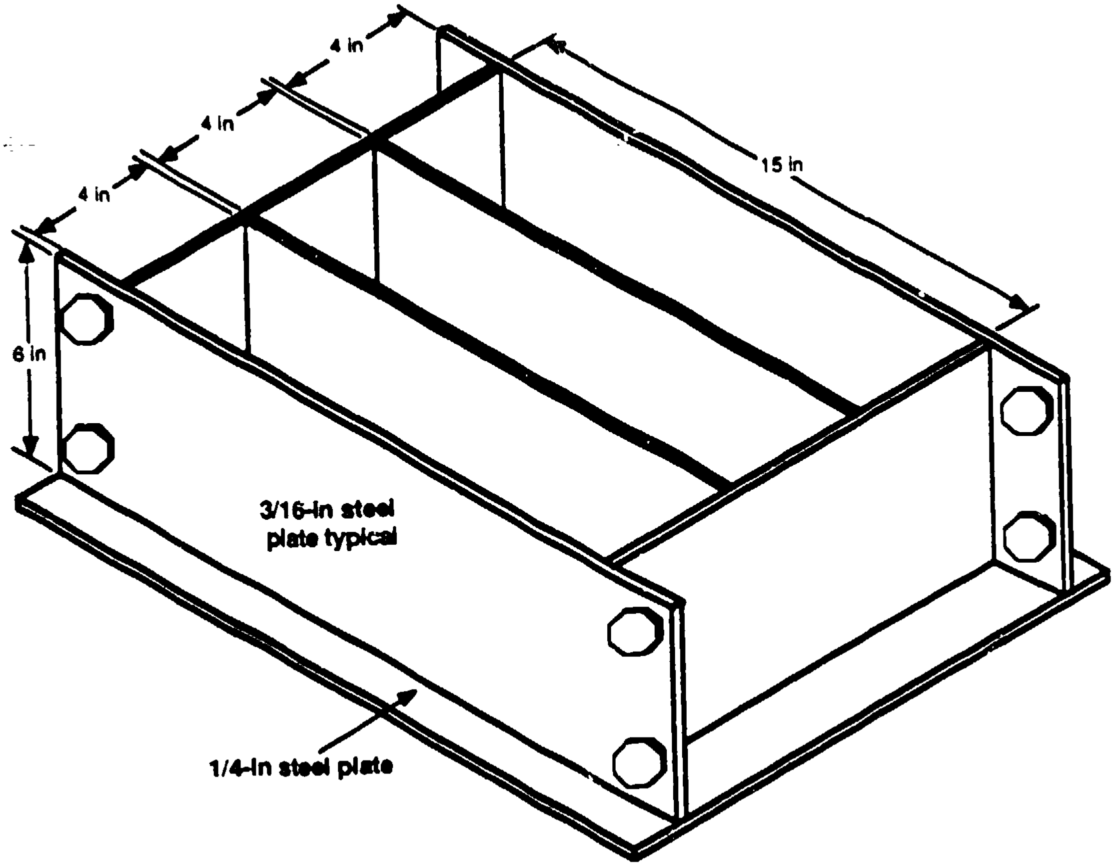


Figure 1. SIFCON steel beam mold.

SIFCON samples were molded as beams, generally 15 in long by 4 in wide by 5 to 6 in deep. Three beams were molded per each steel mold (Fig. 1). From these samples, not only flexure specimens were obtained but also cored cylinder compression specimens, and shear and tension specimens.

Slurry specimens were molded in 3-in steel cube molds, since these molds were available from the previous program.

Approximately 90 percent of the fiber was uniformly sprinkled into the prepared molds. If any fiber clumps appeared, they were removed and resprinkled. The fiber was then vibrated on a shake table for 2 min. From experience, there appears to be negligible further densification after 2 min of vibration. The remainder of the fiber was then sprinkled into the top of the mold, filling the space caused by the settlement resulting from the vibration. Finally the entire fiber bed was vibrated an additional 30 s.

With these fiber placement procedures the fibers would tend to arrange themselves preferentially in the same plane as that of the length and width of all beam specimens.

The sample ingredients were weighed within 24 h of the mix time. Immediately preceding mix time, temperature readings were taken of the cement, fly ash, and water. All weights and temperatures were recorded on the laboratory data sheets. To facilitate the mixing process, the superplasticizer was stirred into the water just before the mixing of the other ingredients. The mixer was then thoroughly dampened with a wet rag to prevent it from drawing mix water out of the slurry.

An impeller-type grout mixer was used to mix all slurries. It was equipped with rubber-tipped paddles that scraped against the walls of the mixer drum with each rotation. This mixer is very effective in breaking up lumps of cement and fly ash and in thoroughly mixing fine-grained slurries. Small conventional concrete drum mixers do not provide the consistent mixing that SIFCON slurries require.

SPECIMEN MOLDING

Typical SIFCON specimens--Just before starting the mixer, approximately 80 percent of the water/superplasticizer solution was placed into the mixer. Seconds before a designated T = 0 time, the mixer was started and the mixer paddles rotated. At the T = 0 time, all fly ash was added first and then all cement was added. When other ingredients such as sand were used, they were added next. Experience has shown this order of mixing produces the least amount of ingredient lumps and therefore the most consistent mixes. After approximately 2 min of initial mixing, the mixer was stopped briefly to allow the cleaning of any caked fly ash and cement from the paddles. The final 20 percent of the water was used in this cleaning procedure if required or was simply added. This cleaning procedure prevented the loss of some ingredients out of the mix. Such a loss would slightly alter the mix proportions. The mixer was immediately restarted and the ingredients allowed to mix until T = 6 min ± 5 s. At this time the mixer was stopped again. A flow measurement (ASTM C-939) was taken immediately (Fig. 2), along with a mix temperature reading. The flow measurement is taken by

Figure 2. Flow cone--test measurements.

filling a calibrated flow cone with slurry to a fixed level, and then measuring the time required to discharge the flow cone. The mix was allowed to sit until T = 9 min ± 5 s, and then the paddles were again rotated for a final 1 min ± 5 s of mixing. Although these procedures and times may seem somewhat arbitrary, they were found through earlier experience to provide consistency and practicality in producing mixes.

Immediately after mixing, the slurry was removed from the mixer, placed in a bucket, and taken to the mold. The slurry was poured over the fiber bed until the spaces between the fibers were infiltrated and the mold was filled. Vibration on the shake table began shortly after about a bucketful of slurry had been placed and was continued for a total of 2 min minimum, depending on the fluidity of the slurry. The 2-min vibration time is a practical infiltration limit for fluid mixes for the size of the mold used. Fluid slurries infiltrate easily, leaving no voids. Only viscous slurries show potential for voids. Some of these slurries were vibrated up to 14 min. In general, the prepared test specimens showed negligible voids. Along with each SIFCON slab, a set of at least six slurry cubes were simultaneously molded.

At T = 30 min and at 15-min intervals thereafter, flow and temperature measurements were taken. These measurements were made to track fluidity over time and to determine the mix open time. Open time is the time available to effectively infiltrate the fibers with a slurry before it becomes too viscous to flow into all the voids.

Sand-type specimens--A special group of preliminary sand mixes was molded (subgroup 4a). The purpose of these mixes was to compare five different commercially available fine-grained sand types. These mixes were produced using the same general procedures, except for the following major deviations.

Because of the purpose of these sand mixes, only cube specimens were needed. Each sand type was studied individually, with all specimen moldings within the sand type done together. The following procedures describe how specimens were produced for the individual sand type. First, a sufficient amount of one particular sand type was completely dried out. After drying,

six different sand proportions of the same sand type were weighed out along with corresponding absorption water that would bring each sand proportion to a saturated surface dry condition. The sand absorption percent value was obtained from the sand supplier. The absorption water was added to the corresponding sands stored in sealed containers. A large batch of all the remaining slurry ingredients was weighed out. These slurry ingredients, except for the six sand proportions, were mixed using typical procedures. After the slurry was mixed, six buckets were filled with 20 lb of the slurry. The six sands that were previously weighed had been proportioned to produce varying sand percentages based on 20 lb of slurry. Next, these six sand proportions were added to the six 20-lb slurry batches. The batches were thoroughly mixed in the buckets, using a drill motor with a mixing paddle attached. After mixing, three cube specimens were molded for each of the six sand batches. Six specimens were also molded using the slurry with no sand in it. After specimen molding, at the typical designated times, flow and temperature measurements of all seven slurry batches were taken.

Composite beam specimens--A special group of specimens was molded as composite beams (Study Group 5). The purpose of these beams was to study the nature of composite beam specimens composed of a layer of SIFCON at the bottom of the beam and only slurry at the top. To mold these specimens required special techniques that deviated from the typical beam specimen molding. These beams were produced using the same general procedures except for the following deviations. Figure 3 illustrates the composite beam specimen in question. To achieve such a beam, a layer of fibers was first placed in the mold and vibrated as usual. The depth of the fibers was the major variable of the study group.

A 0.5-in minimum depth of fibers was added to the predetermined fiber depth. This excess 0.5-in fiber would later be saw cut away to eliminate the edge effects. After fiber placement, a marker was placed at the level of the top surface of the fiber. This marker was used later to measure an accurate fiber depth in order to cut away the excess hardened SIFCON. Next, slurry was mixed using the typical procedures. The slurry was then poured through the fibers and beyond. No vibration was performed after fiber placement. The mold was filled with slurry to a depth that would result in a final overall beam depth of 4 in after cutting. The result was a composite

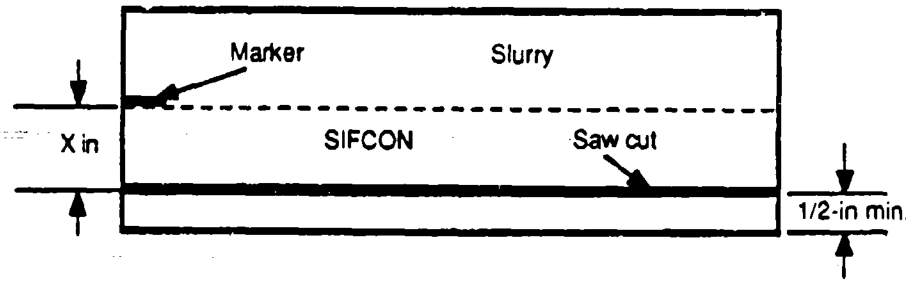


Figure 3. Composite beam specimens.

beam with a layer of SIFCON and a layer of slurry above it with no discontinuous bond between.

SPECIMEN CURING

Initial curing began within 20 min from the T = 0 time with the placement of both SIFCON and slurry specimens in the TCW room. Specimens were allowed to cure for 22 h ± 15 min before the molds were stripped. The 22-h time was selected for program efficiency. Immediately after stripping, the specimens were labeled and placed into a standard water-lime solution in the curing tanks inside the TCW room.

Specimens were allowed to wet cure in the tanks until test time. Specimens were taken out of the water only for coring, cutting, milling, and transporting to the test location. Since the coring, cutting, and milling operations were wet processes, the specimens were never allowed to dry out completely. Specimens were all tested saturated surface dry.

SPECIMEN PREPARATION

SIFCON specimens were prepared for compressive, flexural, shear, and tension tests. Slurry cubes required virtually no preparation. Specimen preparation was performed after a significant sample curing time. After preparation, each specimen was labeled, measured, and returned to the curing tanks until test time.

Compression specimens--SIFCON cored specimens were removed from molded beams. Molded SIFCON cylinders embody a phenomenon known as edge effects. These edge effects occur at the interface of the SIFCON and the mold. At the interface, fibers cannot arrange themselves randomly as at locations away from the edges. Observations indicate that the density of fiber in the area near the edge of the specimen is lower than in the central portion (Fig. 4). This edge area is filled mainly with fiber ends or fibers forced into a vertical alignment. The vertical fibers at the very edge spall off under compressive load and therefore do not contribute to the compressive strength. Experience has demonstrated that molded SIFCON cylinders yield lower and less consistent results. For these reasons, molded cylinders are not believed to be truly representative samples of SIFCON. Thus, to obtain representative samples, all SIFCON specimens were core drilled out of 4- by 6- by 15-in slabs.

Preparation for testing SIFCON compression specimens involved three stages. SIFCON specimens were first cored from a SIFCON beam in a predetermined order. All cores were taken out of the beam in the vertical direction. After coring, both ends of the core were saw cut. The final stage of preparation involved milling both ends of each core. Milling produced smooth and parallel end surfaces normal to the load axis. The samples were milled rather than capped because there were no capping compounds known to be compatible with the anticipated compressive strength and ductility of SIFCON. The core dimensions averaged 2.738 in in diameter by 5.440 in high. Refer to Tables J3 and J4 in Appendix J for the entire range of specimen dimensions.

Flexure and shear specimens--SIFCON flexural and shear specimens were prepared from the molded beams by saw cutting off the irregular tops of the beams (Fig. 5). The saw-cut surface was [illegible] as the tension surface in both types of tests. There were three reasons for cutting these specimens in this manner. First, it is very difficult to mold a top surface that is uniform. Second, all molded surfaces of SIFCON have edge effects. This is also true of top surfaces to some extent. Third, the initial layers of fibers at the bottom of a mold tend to align themselves horizontally with no fibers angled or vertical. Therefore this lower area is also not representative of the SIFCON farther away from any surfaces. This bottom surface

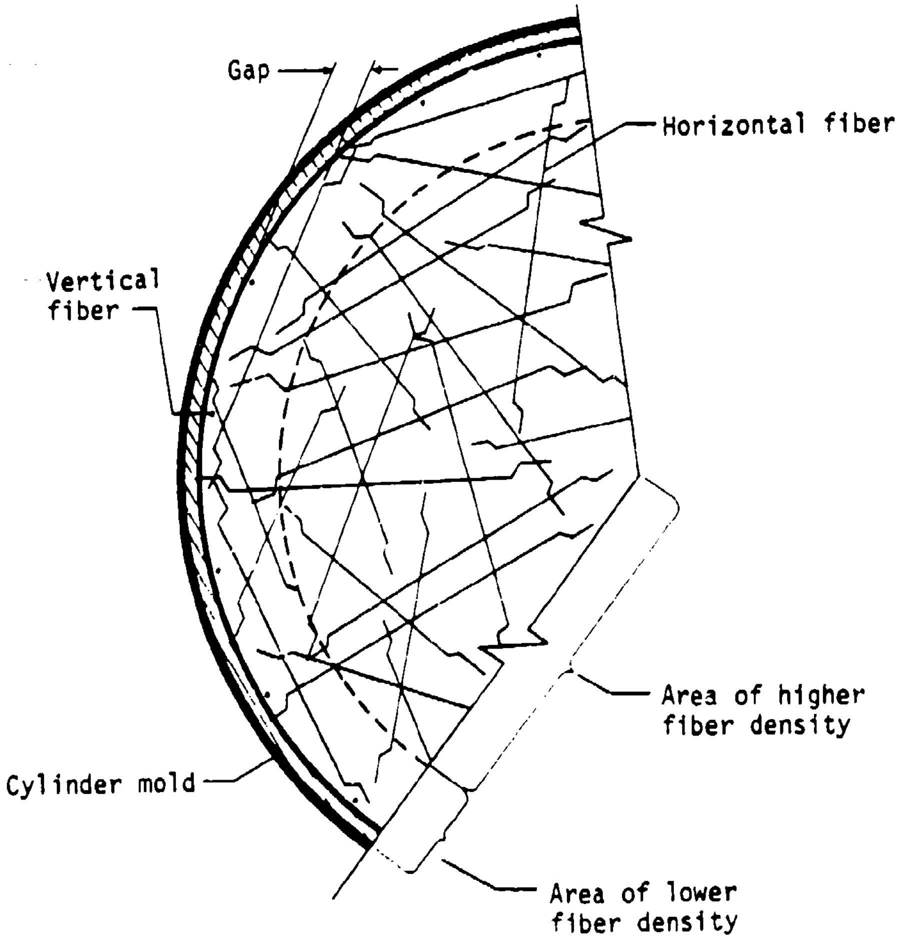


Figure 4. Edge effects in a molded cylinder specimen.

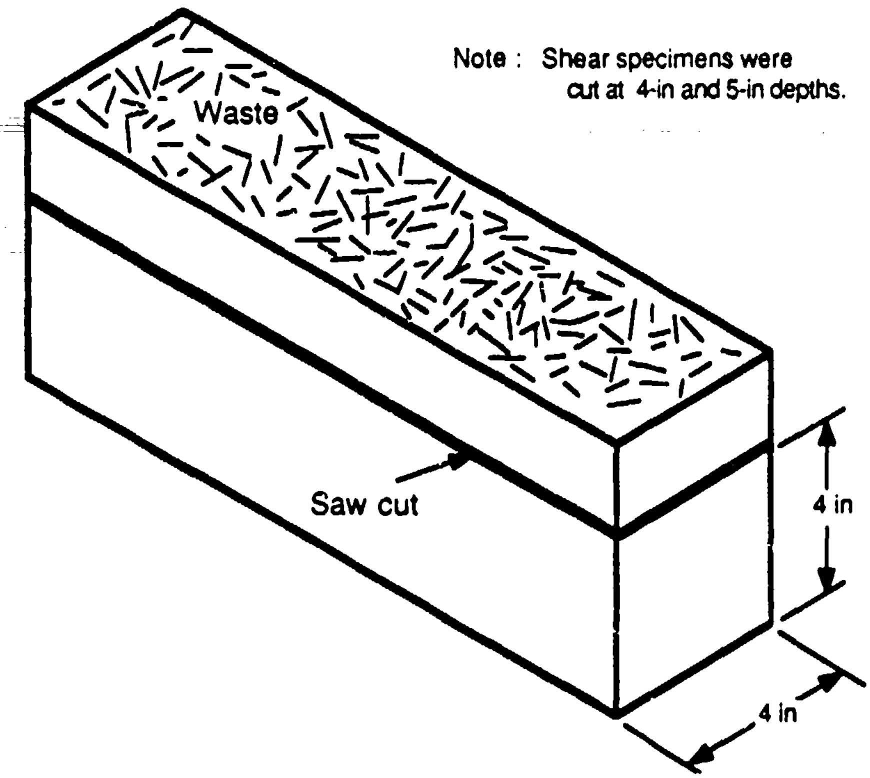


Figure 5. Flexure and shear specimens.

was inverted and tested as the compression surface of the beam for both flexure and shear. It was assumed that the effects of this preferential alignment of fibers would have a negligible effect on flexural and shear strength when placed as the compression surface. Ideally, it would be best to saw cut every surface to totally eliminate edge effects. The costs of preparing such specimens would be very high, making flexural and shear tests of SIFCON impractical.

Composite beam specimens--As discussed earlier, these composite beam specimens were molded differently than the typical flexure specimens. Although the specimens were tested in flexure, the beams themselves also required special preparation after molding. Instead of the tops of the beams being cut off as with the flexure specimens, the bottoms were saw cut off (Fig. 3). Since the tops of the beams did not have any fibers (except for those with a 4-in SIFCON depth), they were rather smooth and level. The bottoms of the beams were saw cut so that the desired depth of SIFCON was obtained. Approximately 0.5 in was cut off. The resulting specimen was a composite beam with no bottom edge effects.

Variable depth beam specimens--These variable depth specimens were molded using the typical flexure specimen procedures. The specimens for this study group were obtained by saw cutting the desired depth of beams from these typically molded specimens. The specimens were cut from 1 to 5 in in depth from these molded beams. Except for the 5-in-deep specimen, two cuts were made on each beam. First, either a 3- or 4-in specimen was cut off the bottom of the molded beam. From the remainder of the beam where a 3-in specimen had been cut, a 2-in-depth specimen was cut. From the remainder of the 4-in specimen, a 1-in-depth specimen was cut. The 5-in-depth specimen required an entire beam and a single cut that removed the top edge effects. Figure 6 shows these required cuts. During flexure testing, the saw-cut surface was placed as the tension surface.

Tension specimens--SIFCON tension samples were molded as beams similar to flexure and shear samples. The only two differences were: (1) they were molded with wooden inserts centered on each side of the mold to produce an I-shaped specimen, and (2) they were only 13 in long instead of 15 in. Two 2-in-thick specimens were saw cut out of each of these beams. In an attempt to eliminate the edge effects and to force a failure in a middle section, each specimen was saw cut at varying spacing. These saw-cut notches were spaced from 2 to 0.5 in apart and cut to a depth forming a parabolic shape. Some specimens were totally milled to this parabolic shape. The saw cuts were made at varying spacing to determine the extent of concentrated stresses at the cuts. Figures 7 and 8 picture the six different types of specimen notches after completion of all cuts.

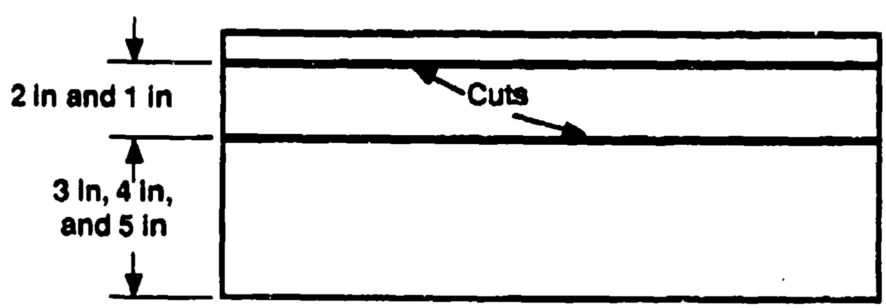


Figure 6. Variable depth beam specimens.

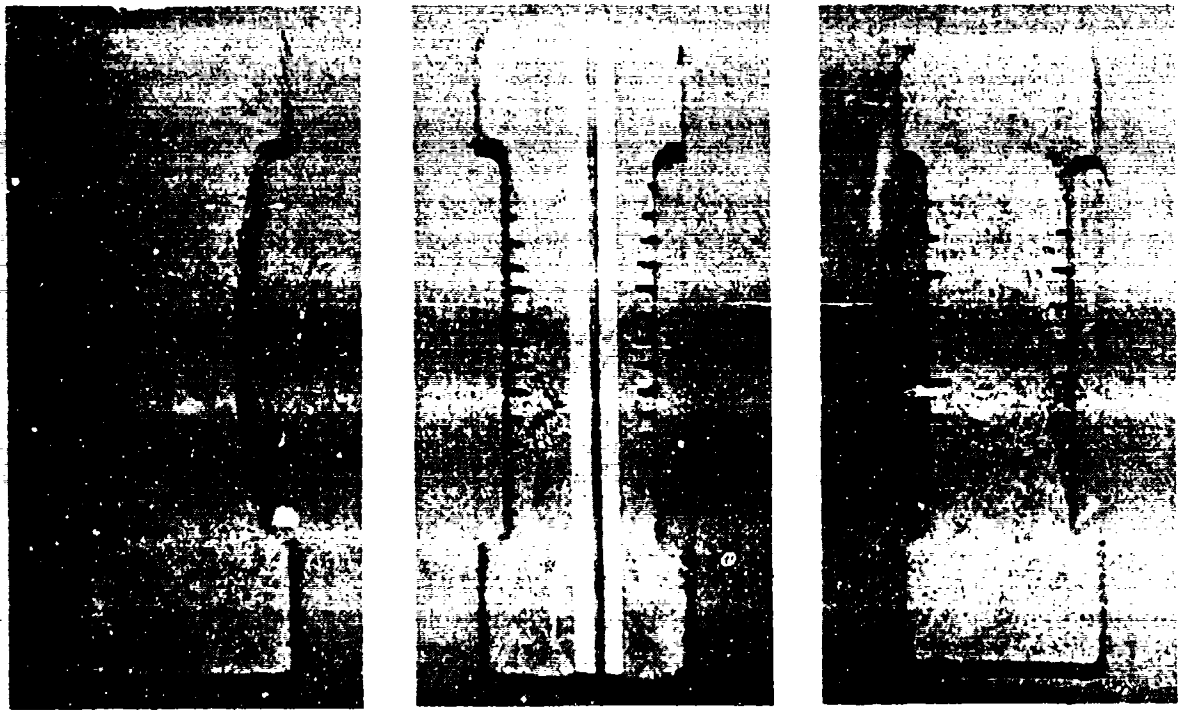


Figure 7. Tension specimens, milled, 0.5- and 0.75-in spacing of notches.

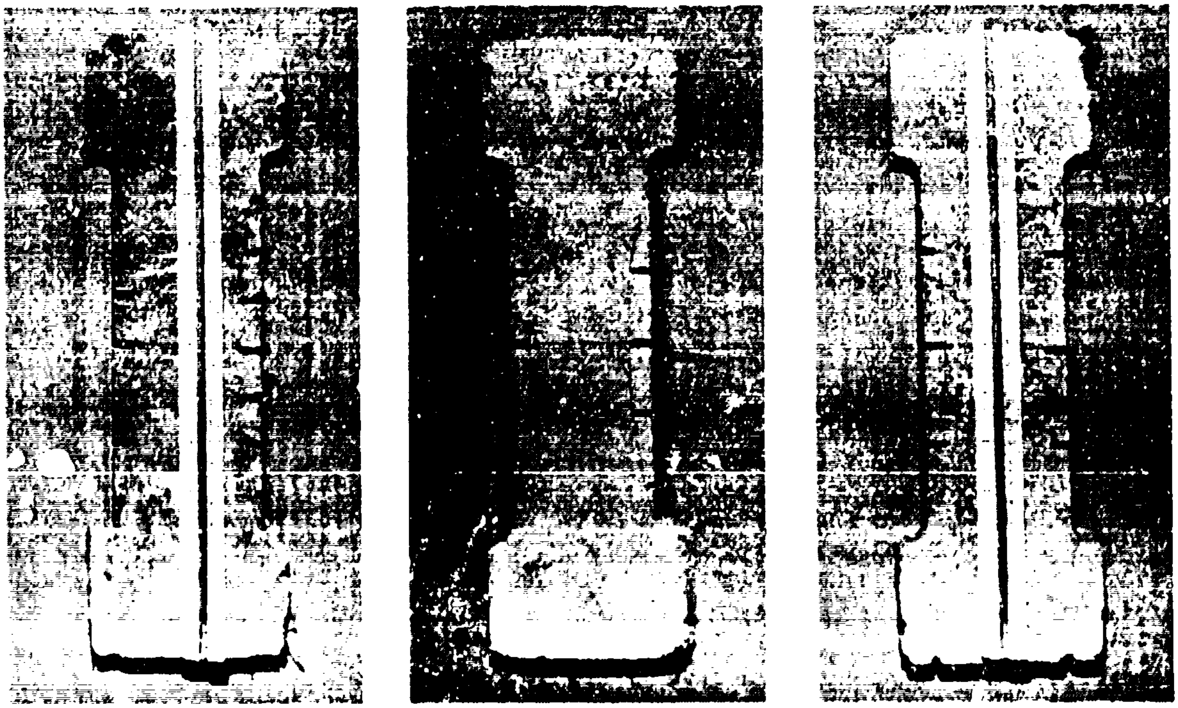


Figure 8. Tension specimens, 1-, 1.5-, and 2-in spacing of notches.

SPECIMEN TESTING

After preparation and curing, the specimens were transported to the testing machine in cushioned insulated containers. SIFCON specimens were tested saturated surface dry on the Tinius-Olsen testing machine described in Table L1. Load-versus-deflection curve data were obtained for nearly all SIFCON specimens. Slurry cubes were tested for ultimate strength only. Generally, a test series was composed of four or five SIFCON specimens and three corresponding slurry cubes. All SIFCON specimens were tested at 30 days after molding. Slurry cubes were tested at 7 and 30 days.

SIFCON compression specimens were tested according to ASTM C-39. This method involved the application of a uniform axial stress upon the top and bottom planes of a cylindrical specimen. As the load was increased a data acquisition system recorded the load-deflection characteristics of the test specimen.

SIFCON has not been tested extensively in flexure, shear, or tension; therefore, the fabrication and/or the selection of appropriate test methods for these tests was a major consideration.

Conventional fiber concretes have been extensively tested in flexure, based on an ASTM* Standard (ASTM C-1018) developed for this purpose. This standard was used to fabricate and test SIFCON in flexure in this program. Figure 9 illustrates the test method used in the flexure tests. The method involves the application of two point loads at locations dividing the beam into equal one-third distances from the supports. This is designated as a third point loading configuration. This configuration loads a beam specimen with a uniform flexural stress between the middle one-third span. These flexural stresses were calculated from the applied load and the beam geometry. As the load was increased a data acquisition system recorded the load-deflection characteristics of the test specimen.

In relation to shear and tension testing, this program was limited to a preliminary study of an appropriate test method for each. Figure 10 illustrates the test method under investigation for shear tests. This method

*American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

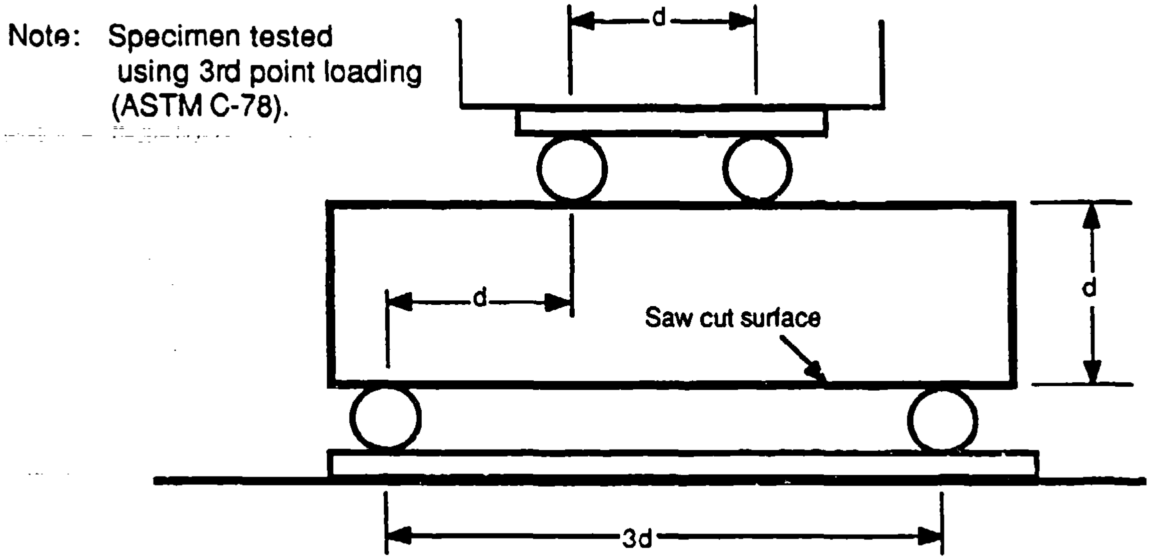


Figure 9. Flexural test method.

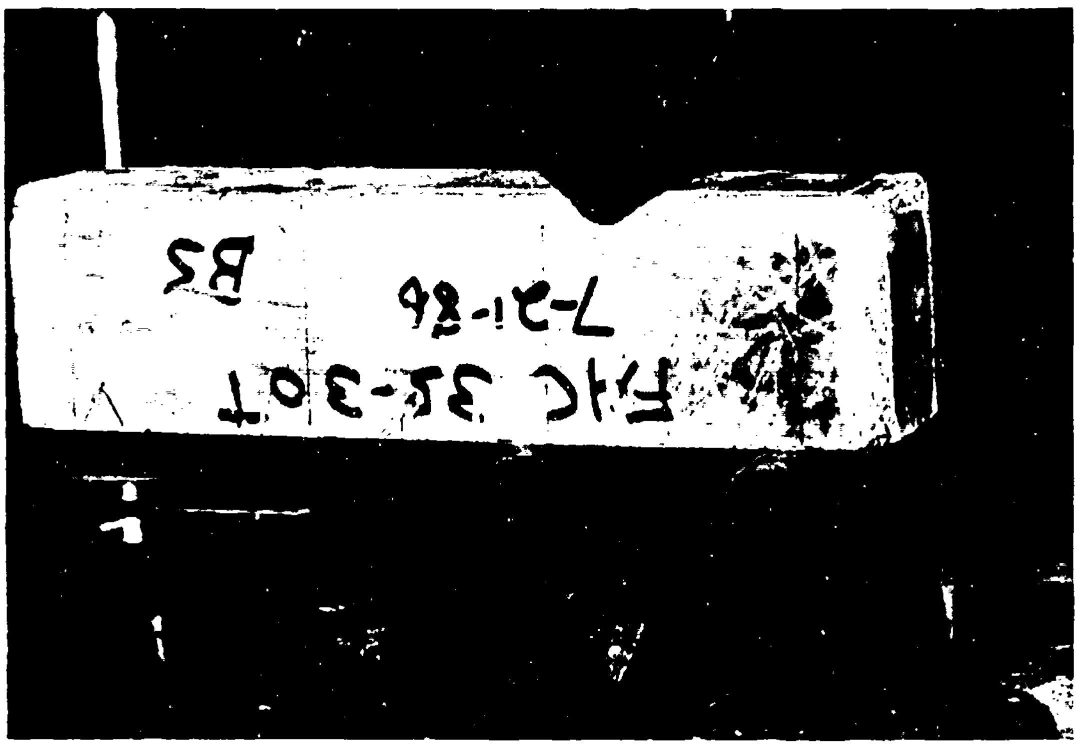


Figure 10. Shear test method.

applied a single point load at the center of a small span between two supports. It was hoped that with a small span length the beam specimen would be loaded principally with shear stresses and with negligible flexural stresses. These shear stresses were calculated from the applied load and the beam geometry. The load-deflection characteristics of the specimen were recorded with a data acquisition system.

Figure 11 illustrates the test method and apparatus used for tension tests. The test method involved the fabrication of specially shaped specimens (Figs. 7 and 8) as previously described. The method applied tensile stress by gripping the ends of these specimens and applying an axial load. The load-elongation characteristics of the specimen were recorded with a data acquisition system.

All SIFCON specimens were loaded well beyond the deflection at the ultimate strength to demonstrate a complete load/deflection curve. SIFCON has a very significant load-carrying capacity even after ultimate strength. Figures 12 through 16 show typical failure modes for flexure, composite beam, variable depth beam, shear, and tension tests, respectively.

DATA ACQUISITION AND REDUCTION

At all stages of SIFCON production and testing, data were recorded and observations made and recorded on the laboratory data sheets. During specimen testing, load/deflection data were acquired and saved directly from the electronic output of the testing machine using an analog-to-digital converter and a 512K Macintosh computer (Fig. 17). These data were reduced using computers producing either stress/strain or load/deflection curves, depending on the type of test performed. A complete, detailed, step-by-step description of the data acquisition and reduction procedures is presented in Appendix K.

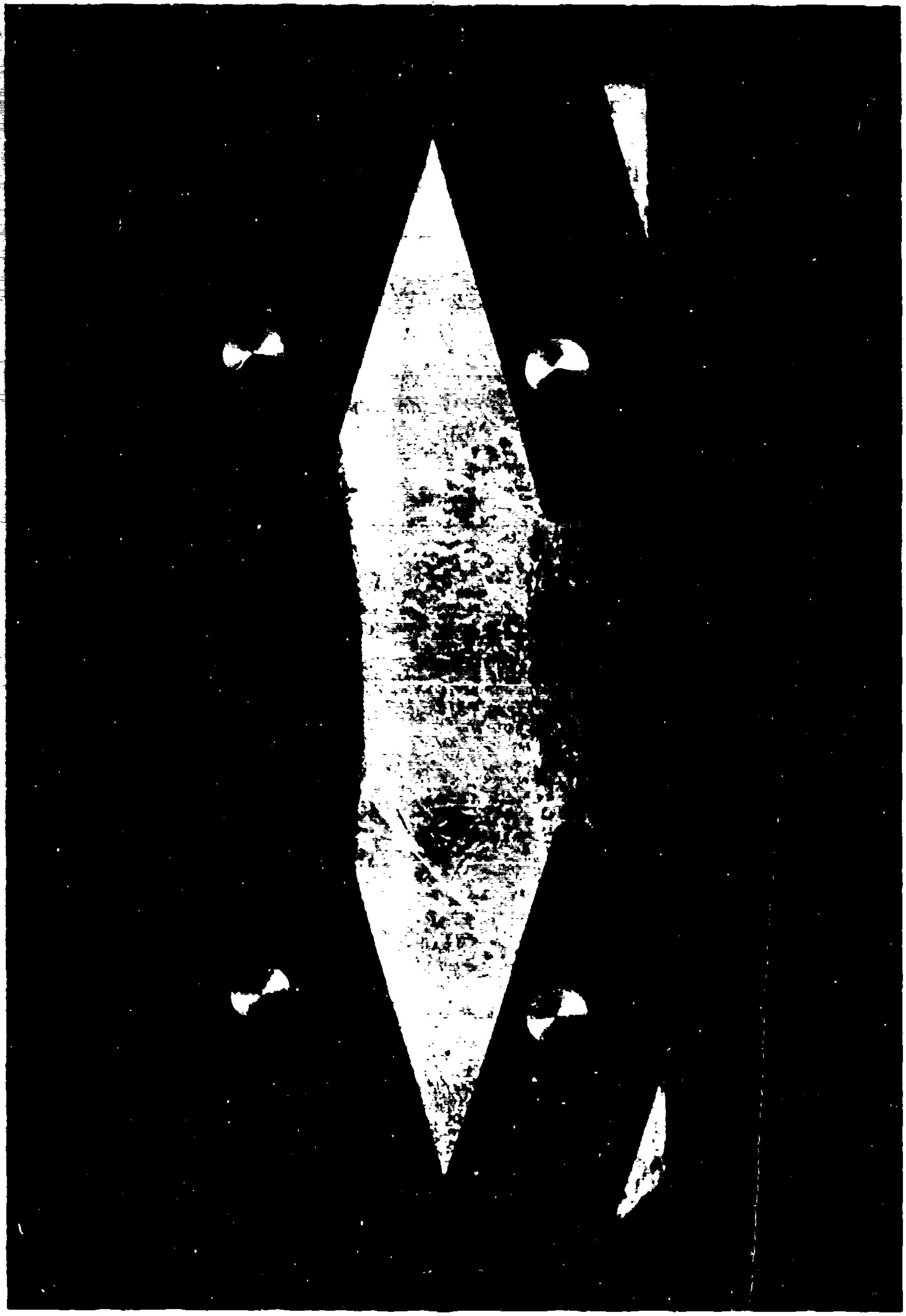


Figure 11. Tension test method.

Figure 12. Typical flexural failure mode.

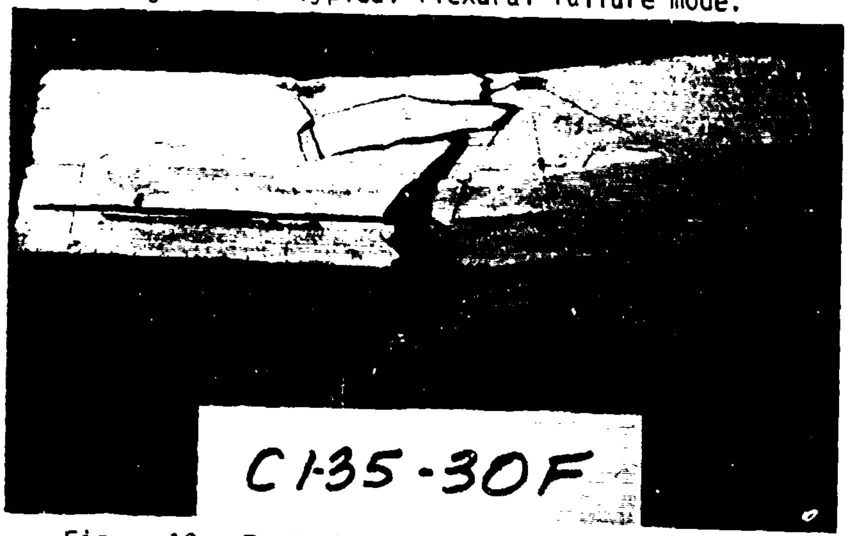


Figure 13. Typical composite beam failure mode.

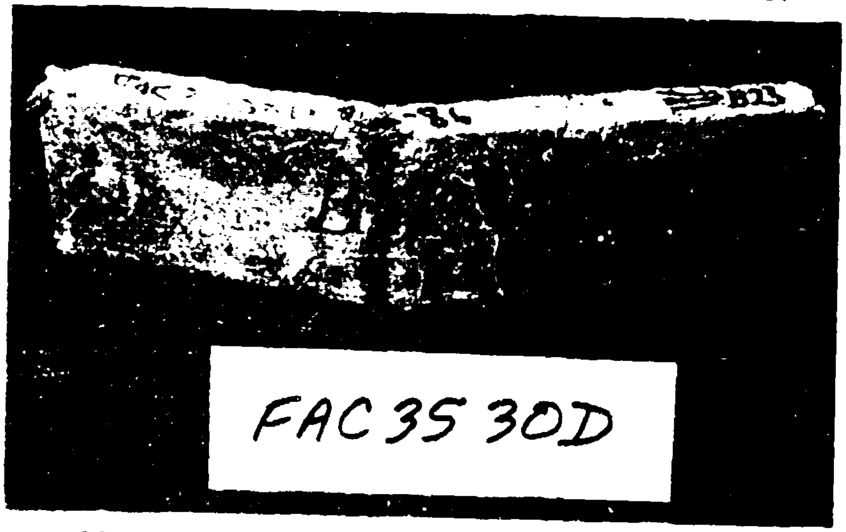


Figure 14. Typical variable depth beam (1 in) failure mode.

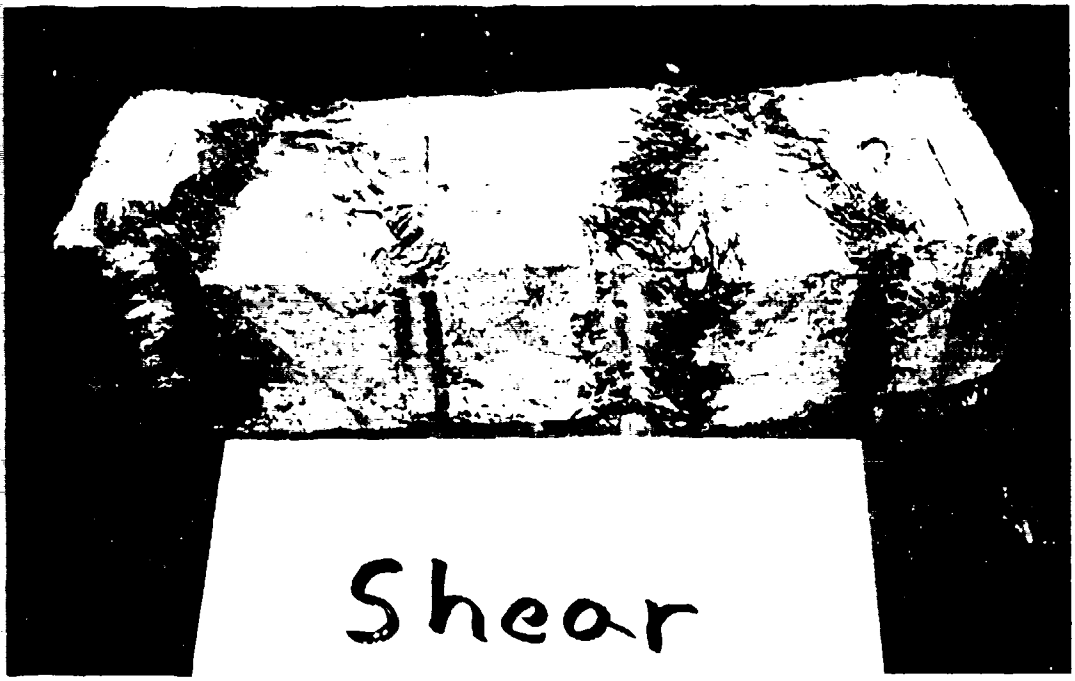


Figure 15. Typical shear failure mode--two tests on one specimen.

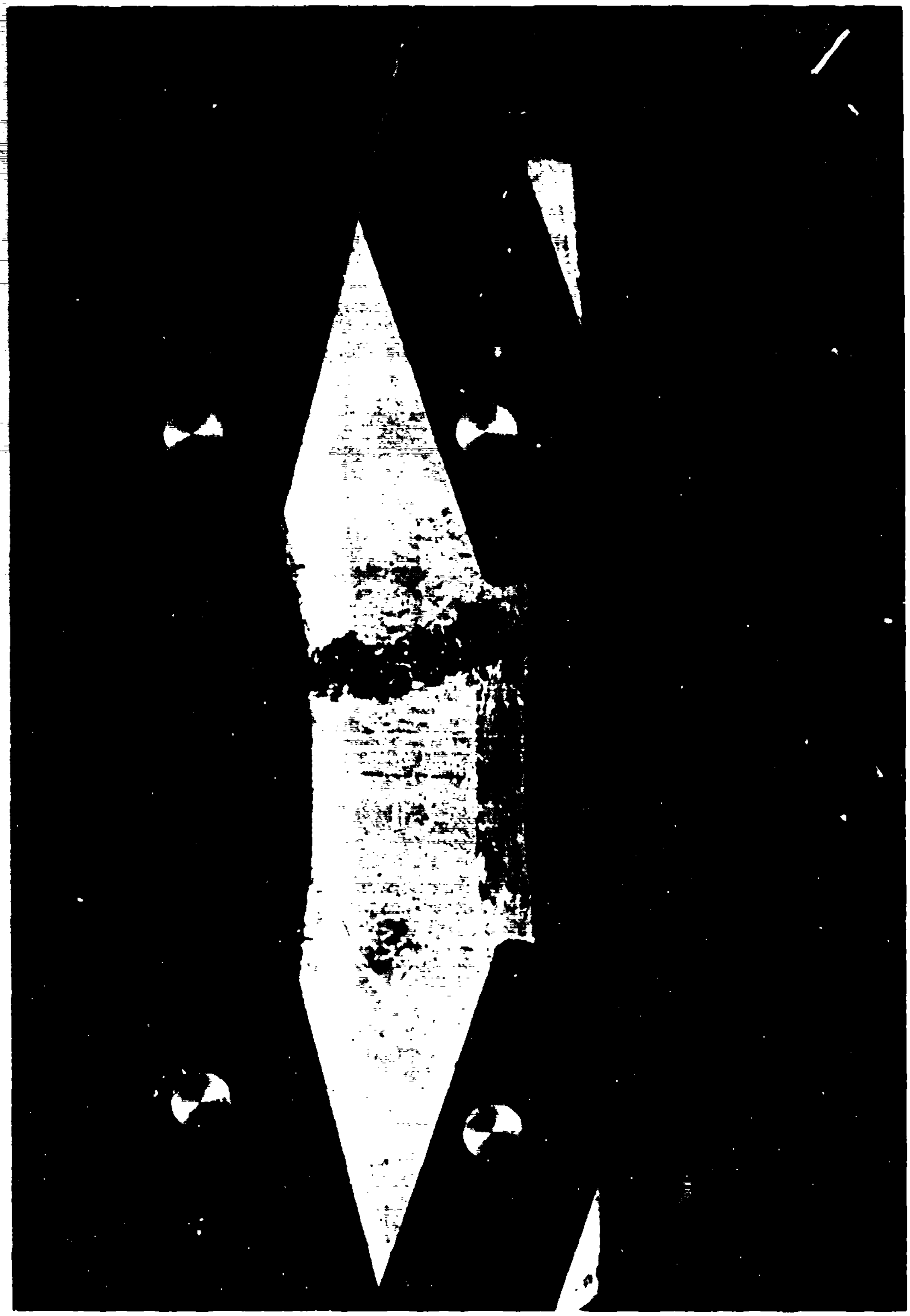


Figure 16. Typical tension failure mode--milled specimen.

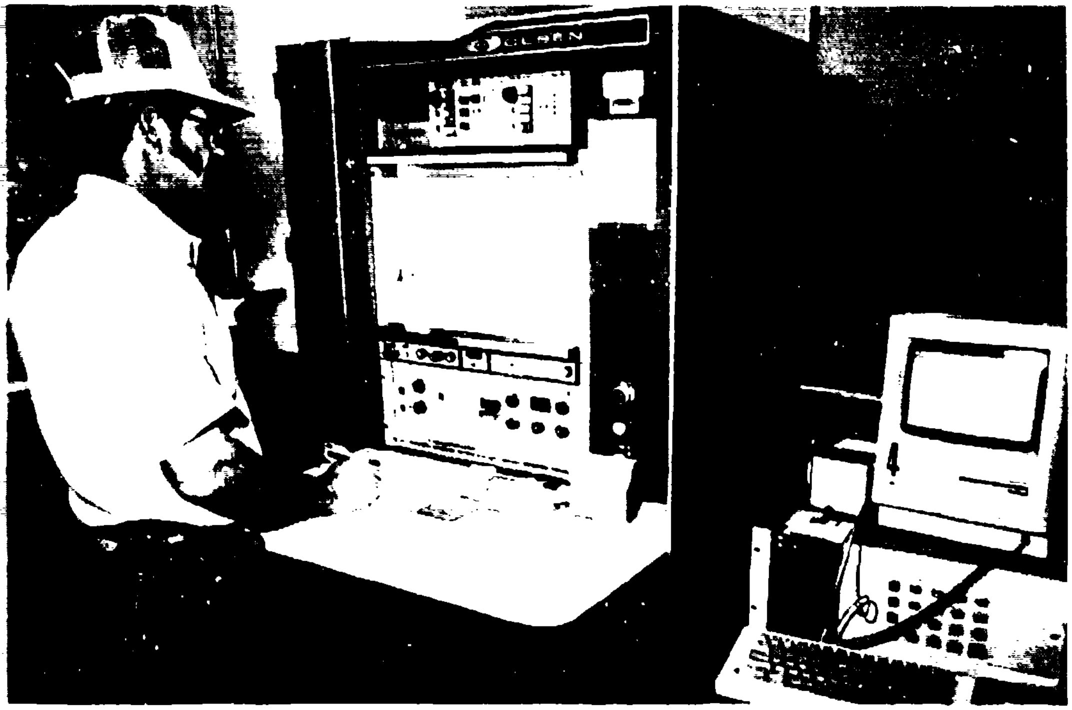


Figure 17. Test data acquisition setup.

III. PROGRAM TEST RESULTS

GENERAL

This section reviews the detailed results of the test program. All test results are presented in either tabulated or plotted form in the applicable appendixes. Generally the arrangement of all data is in the order of discussion of each study group. The phrase "study group" or "group" is used in this report to refer to a set of mixes where everything is held constant except one variable.

Mix identification--Every mix produced was given a distinct identification code. When more than one mix of the same proportions as a previous one was made, the identification code was similar but was distinguished by the addition of a letter designation at the end. All mixes identified with a "CW" prefix represent a mix study group where the water-to-cement ratio was being varied. These mixes are followed by two sets of digits. The first set represents the water/(cement + fly ash) (W/C + FA) ratio in percent, while the second set represents the fly ash/(cement + fly ash) (FA/C + FA) value in percent. For example, the mix identified as CW 38-30 has a W/C + FA ratio of 0.38 and a FA/C + FA percent of 30. Mixes identified with a "FAC" prefix represent mixes where the fly ash to cement proportion is varied. The digits that follow represent the same values as the CW mixes. All mixes with variable fibers are identified with letters and digits resembling the fiber-type name (Table 1) followed by two sets of digits. For example, a mix identified as Z 5/5-35-30 F contains Dramix ZL 50/50 fibers and a slurry with the W/C + FA ratio of 0.35 and FA/C + FA percent of 30. Mixes identified with an "S" prefix represent those where sand is the variable. These mix identifiers contain three sets of digits. The first set represents the percent of sand with respect to cement, the second represents the W/C + FA ratio in percent, and the third represents the FA/C + FA value in percent.

The mix designs used for each separate study group are contained in Appendix A. As shown, some mixes occur in more than one study group. The mix design tables include all mix ingredients and proportions. The tabulated weights are those of the actual laboratory mixed batches.

Fluidity--A major consideration of the previous program was to study the fluidity of various SIFCON slurries. This is an important SIFCON parameter because only slurries of appropriate fluidity will successfully infiltrate steel fibers. If a slurry is too viscous, it will either only partially infiltrate the fibers, leaving voids in the SIFCON, or simply set on top of the fiber bed and not infiltrate at all. The fluidity measurements of the program were performed so that correlations could be made with the previous program if needed. They also added to an existing data base of SIFCON mix information.

Fluidity measurements were taken using the ASTM C-939 flow test. This is a standard test method used to measure relative fluidity of low-viscosity cementitious grouts and slurries.

Table B1 (Appendix B) presents tabulations of all flow measurements for each of the mix designs. The top of Table B1 shows the times in minutes when measurements were taken. These times are with respect to the time when ingredient mixing began (T = 0). The tabulated numbers within the table are the flow measurements in seconds. Measurements were taken until the mix was too thick to flow or until T = 3 h. Some mixes were too thick to measure even at the 7-min time. These do not show a time but instead show the term "thick." Thick slurry mixes with flow measurements exceeding approximately 90 s are generally too thick to pass through the flow cone and therefore measurements could not be taken. The flow measurements also indicate a useful parameter called open time. Field observation shows that a practical open time for most fibers can be defined by a flow measurement of less than approximately 50 s. Open time is indicated in Table B1 by the vertical lines.

Specimen tests--In general, a set of three slurry cubes, four SIFCON compression specimens, and five SIFCON flexure specimens were tested at 30 days for each mix. These tests produced individual load-versus-deflection curves. Compression curves were then reduced to stress-versus-strain curves. Appendix C presents all the SIFCON stress-versus-strain curves for the compresssion and the load-versus-deflection curves for flexure tests for each of the study groups (Figs. C1 through C86, and C91). The shear (Figs. C87 through C90), tension (Figs. C92 through C96), and special study tests were treated in a similar manner and are also contained in Appendix C.

Figures 18-21 illustrate typical or generic stress/strain or load/deflection curves showing the location of selected values on these compression, flexure, shear, and tension curves. These figures illustrate the high strength and ductility of SIFCON. In compression (Fig. 18) SIFCON displays an elastic range up to Point A on the figure, the proportional limit. The slope of this curve can be designated as the SIFCON modulus of elasticity (Slope 1). On many of the stress/strain curves this slope was not always perfectly linear. When it was not linear, a linear regression was performed to define the slope. The procedures used to obtain this slope are contained in Appendix K. For the curves with nonlinear slopes the proportional limit was estimated when performing the linear regression. Often SIFCON in compression also displays a second nearly linear but nonelastic range. When this behavior occurred, the stress/strain values at B and C were estimated, defining a corresponding Slope 2. Test specimens continue to strain and carry load up to an ultimate strength at Point D, which is considered to be the failure point. There is no visible failure when the specimen reaches Point D. The deflection, however, is noticeable. After this strength is reached, the material continues to strain and carry a load, but in an erratic and unpredictable manner. When actual failure is noticeable, definite shear planes are produced. For Dramix and Fibercon fibers, the shear planes are generally at approximately 45 deg, while those of Xorex fibers are closer to horizontal planes. The specimens seldom crumble like conventional concretes. They could be strained in excess of 0.50 in/in and still carry a significant load. It is this tremendously ductile behavior that gives a SIFCON structure its excellent blast pressure resistance. SIFCON tested in flexure (Fig. 19), shear (Fig. 20), and tension (Fig. 21) displays similarly shaped curves. However, there is no secondary slope.

Appendix D also presents a tabulated summary of selected compression, flexure, shear, and tension values taken from the stress/strain and load/deflection curves (Tables D1-D7). Each table presents the test data from the applicable study group. Each table organizes the data according to subgroup and then according to the specific type of test. The introduction to the appendix explains in detail the specific contents of the data in the tables. Also contained in Table D8 are all slurry 7-day ultimate compressive strengths.

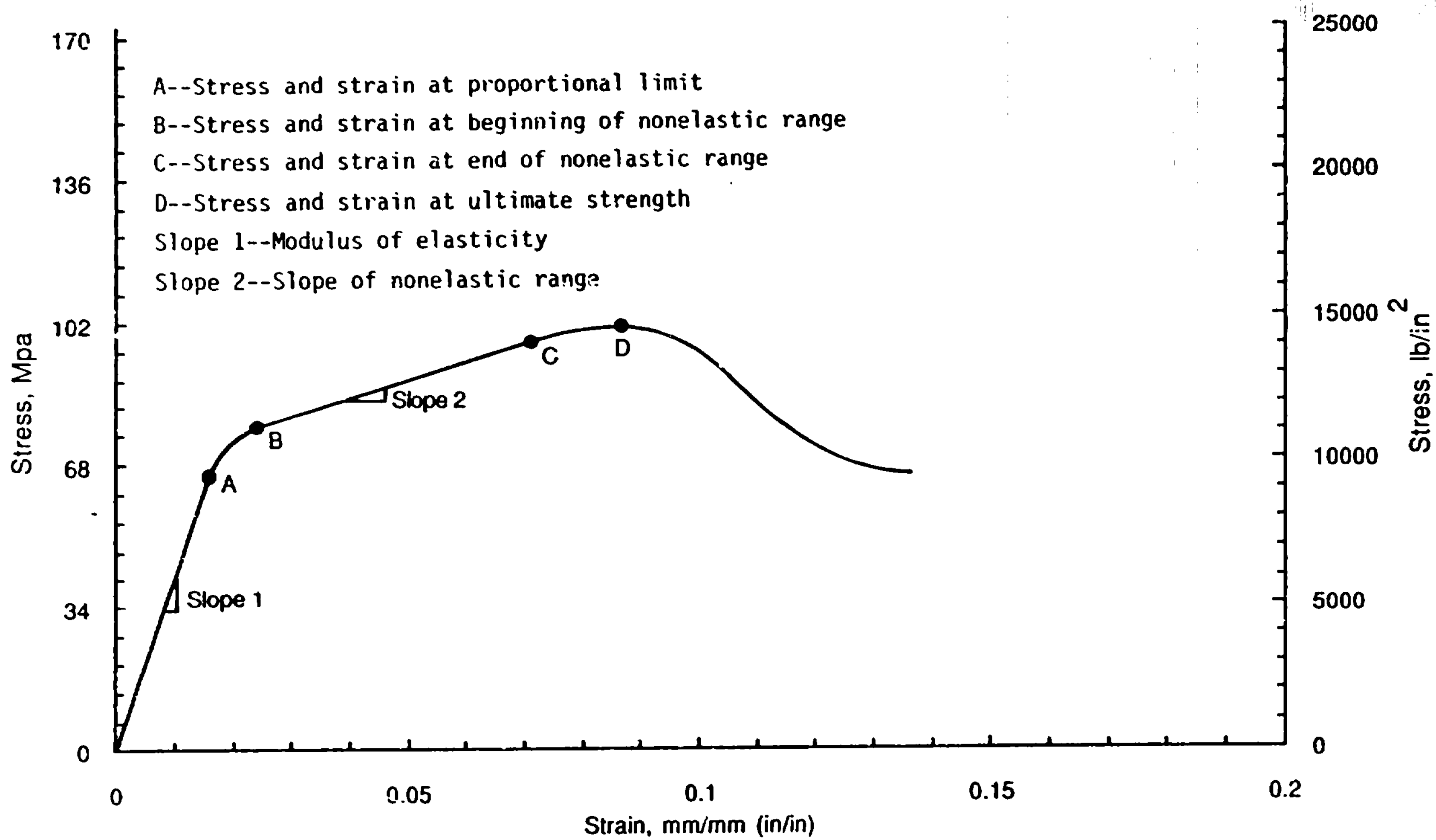


Figure 18. Typical average compression data.

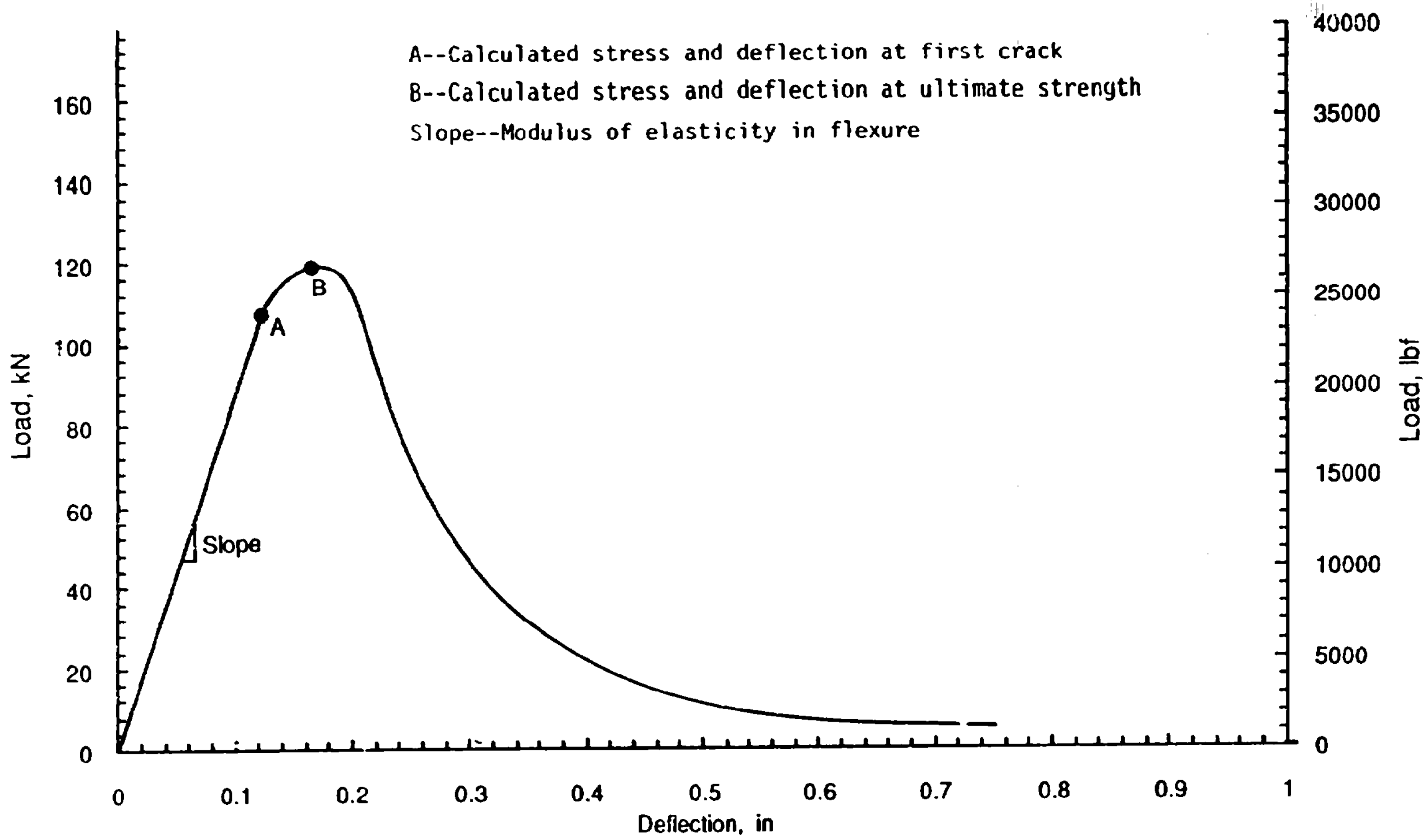


Figure 19. Typical average flexural data.

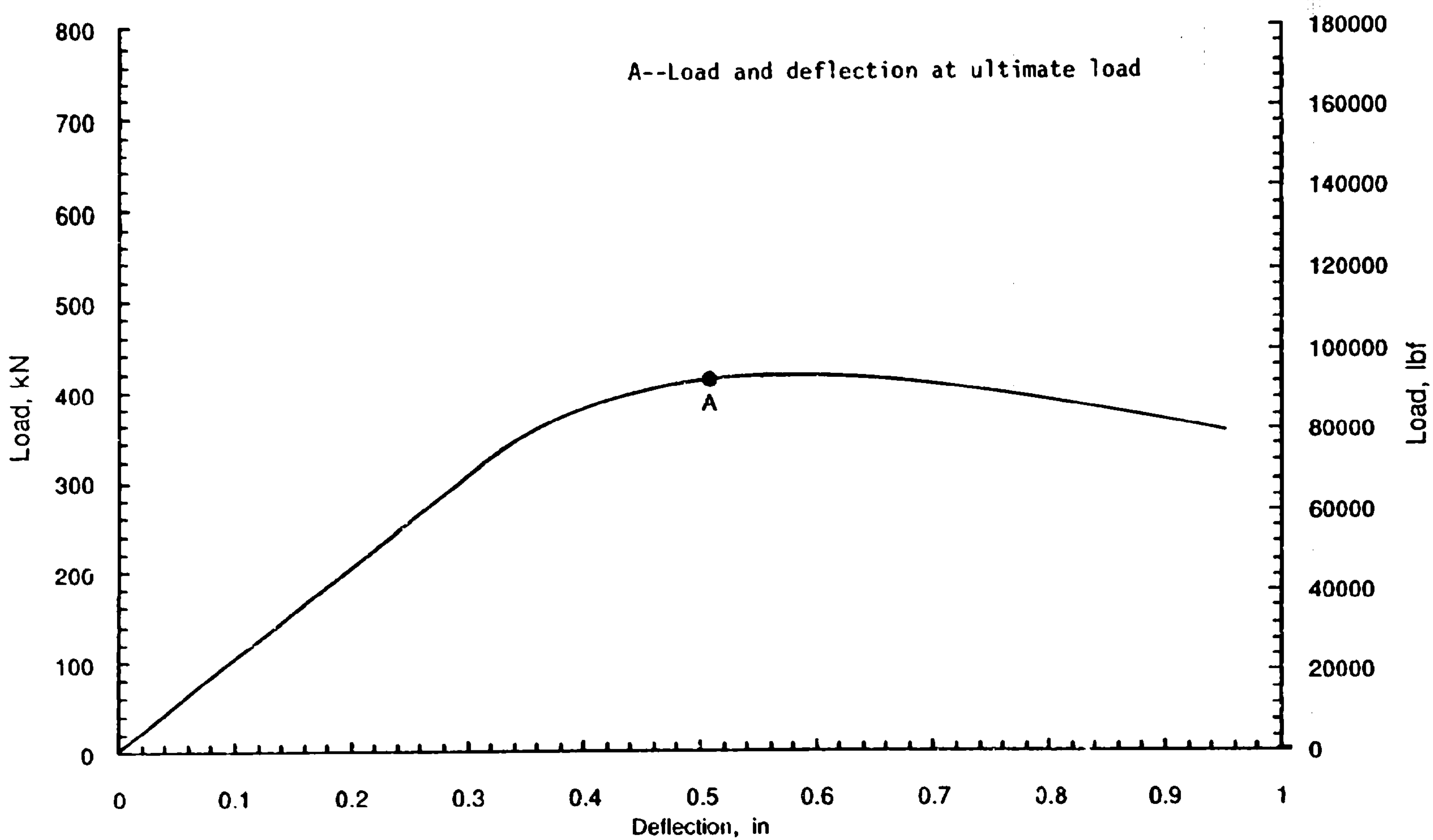


Figure 20. Typical average shear data.

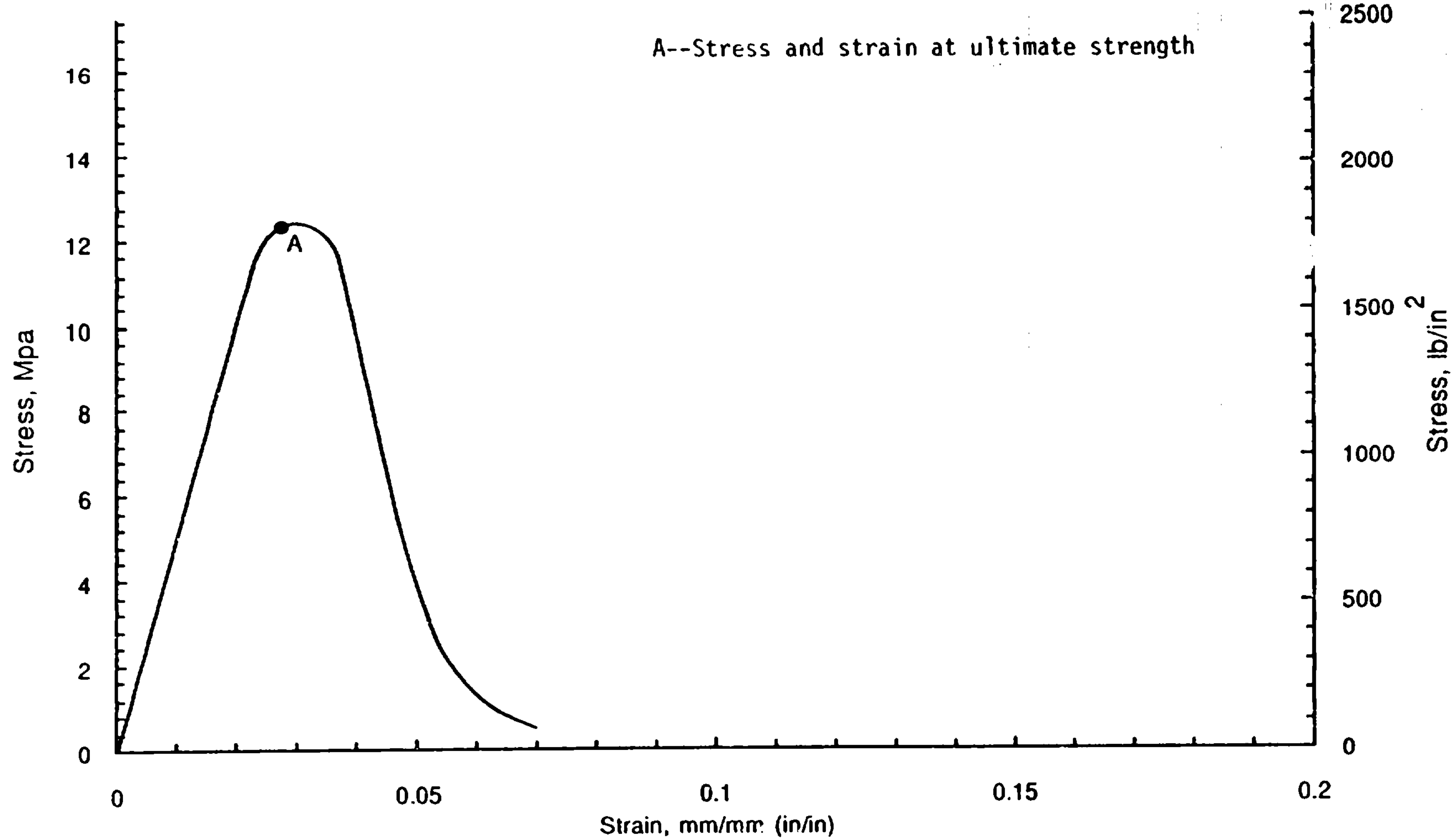


Figure 21. Typical average tension data.

Test result summaries--All the test results for the various parameters within a specific study group are summarized in graphs presented either in the discussion within the specific study groups or in Appendixes E through I. Representative graphs are interpreted in the following discussion of the study group results. These graphs were computer-generated using a Macintosh computer application called Cricket Graph. The graphs are presented as scatter plots with computer-calculated curve fits. In general, either a simple linear regression or an exponential regression curve fit was selected. The decision as to the best curve fit was based on the coefficient of simple correlation value calculated by the computed application, and on practical experience.

Quality control data--The program quality control data are documented in Appendix J. Table J1 lists all the mixes according to the chronological order in which they were molded. The table shows the time of day that the mixing began, the TCW ambient temperature prior to mixing, and the temperature of each mix after 7 min of the mixing process (T = 7). The ambient temperatures were well controlled, ranging from 68 to 71 °F except for the one mix noted. Table J2 presents the environment control of the TCW room, of mixing ingredients before mixing, and mix temperature after 7 min for each of the study groups. Averages, as well as minimum and maximum values, are also given. Again, relatively good temperature control was obtained.

Dimensional control of the SIFCON specimens and slurry cubes is presented in Tables J3 and J4. Again, averages, maximums, and minimums are given for each group. In general, very satisfactory control of all specimen dimensions was accomplished. The average height-to-diameter ratio of all SIFCON cored specimens of 1.987 was very close to the goal of 2. The average height-to-width ratio of all typical beam specimens (including both flexural and applicable shear specimens) of 1.004 was very close to the goal of 1. The goal of 3 in for a height of all slurry cube specimens was closely approximated with the average of 3.082 in. Except for the specimens noted in the tables, the range of specific values was also within acceptable limits.

Table 2 summarizes the repeatability of results of those specimens that had the same proportions. These results will be treated in the discussion of Study Group 2.

STUDY GROUPS--VARIABLES

Study Group 1--Water versus cement plus fly ash

General--This study group was designed to investigate the effects on flexural strength of varying the water content. All other mix proportions were kept constant. Table A1 (Appendix A) contains all mix designs for this study group.

The major consideration of this program was to study flexural material properties. Compression specimens were also tested. The purpose of these compression tests was to compare and correlate between this program and the previous compression program.

Fluidity--Fluidity measurements were taken for all mixes. All these data are contained in Table B1 (Appendix B). In general, an increase in the water content results in an increase in fluidity. For example, the mix with the lowest W/C + FA ratio (CW 28-30) was too thick to get a flow measurement, while the mix with the highest (CW 43-30) showed the highest fluidity.

Mix open time is the time after initial mixing at which a given mix becomes too viscous to assure proper fiber infiltration. In this program the mix open time is represented by the time required for a mix to reach a viscosity with a flow measurement of 50 s. A mix with a flow measurement of 50 s has been demonstrated to be fluid enough to safely infiltrate most fibers. The open times for mixes in this group increased as the W/C + FA ratio increased. The fluidity and open times of the mixes of this program closely paralleled comparable mixes of the previous program.

Compression--Specimens were prepared to be tested in compression from all mixes in this study group. Figure E1 (Appendix E) shows the range of SIFCON and slurry ultimate strengths obtained for this study group. In general, a lower W/C + FA ratio results in higher compressive strength. This trend is observed in both the slurry as well as SIFCON strengths. These ultimate strength trends are representative of all the other strength values taken from the stress/strain curves. All these other values are contained in Table D1 (Appendix D).

Figure E2 compares the compression tests of this program with those of the previous program. The repeatability of results was not as good as expected. SIFCON ultimate strengths of comparable mixes were consistently lower in this program. The lower strength trend was consistent throughout the other study groups as well. The slurry strengths, however, were reasonably consistent with the previous slurry strengths. This trend in slurries was also true in the other study groups. An attempt was made to isolate reasons for this discrepancy. Study Group 7 contains this discussion and conclusions.

Flexure--Various different parameters from the SIFCON flexure data were compared with the W/C + FA ratio. These parameters include modulus of rupture (ultimate strength), first crack strength, flexure modulus of elasticity, first crack toughness, three toughness indexes, and two index ratios. The toughness values give an indication of the energy absorption capability of the particular SIFCON test series under consideration. All these parameters are specified and defined in ASTM C-1018. The results are tabulated in Table D1.

Figure 22 presents the strength comparisons of both modulus of rupture and first crack strength. Both curves demonstrate a lowering of strength with an increase in the W/C + FA ratio. This is what would be expected. From the simple linear regression curve fit of the data, the modulus of rupture values ranged from 5420 to 4230 lb/in^2 for the W/C + FA ratios from 0.275 to 0.425 respectively. The range in strengths at first crack for the same W/C + FA ratios was 3460 to 2480 lb/in^2.

The modulus of elasticity data plotted in Figure E3 were too scattered to show any definite trends.

Several SIFCON toughness parameters were compared with the W/C + FA ratio. The comparisons of first-crack toughness are presented in Figure 23. There is a lowering trend of first-crack toughness with an increase in the W/C + FA ratio. From the simple linear regression curve fit, the first-crack toughness ranged from 490 to 150 in-lb for W/C + FA ratios from 0.275 to 0.425, respectively. The plots of I_5, I_{10}, and I_{30} toughness indexes

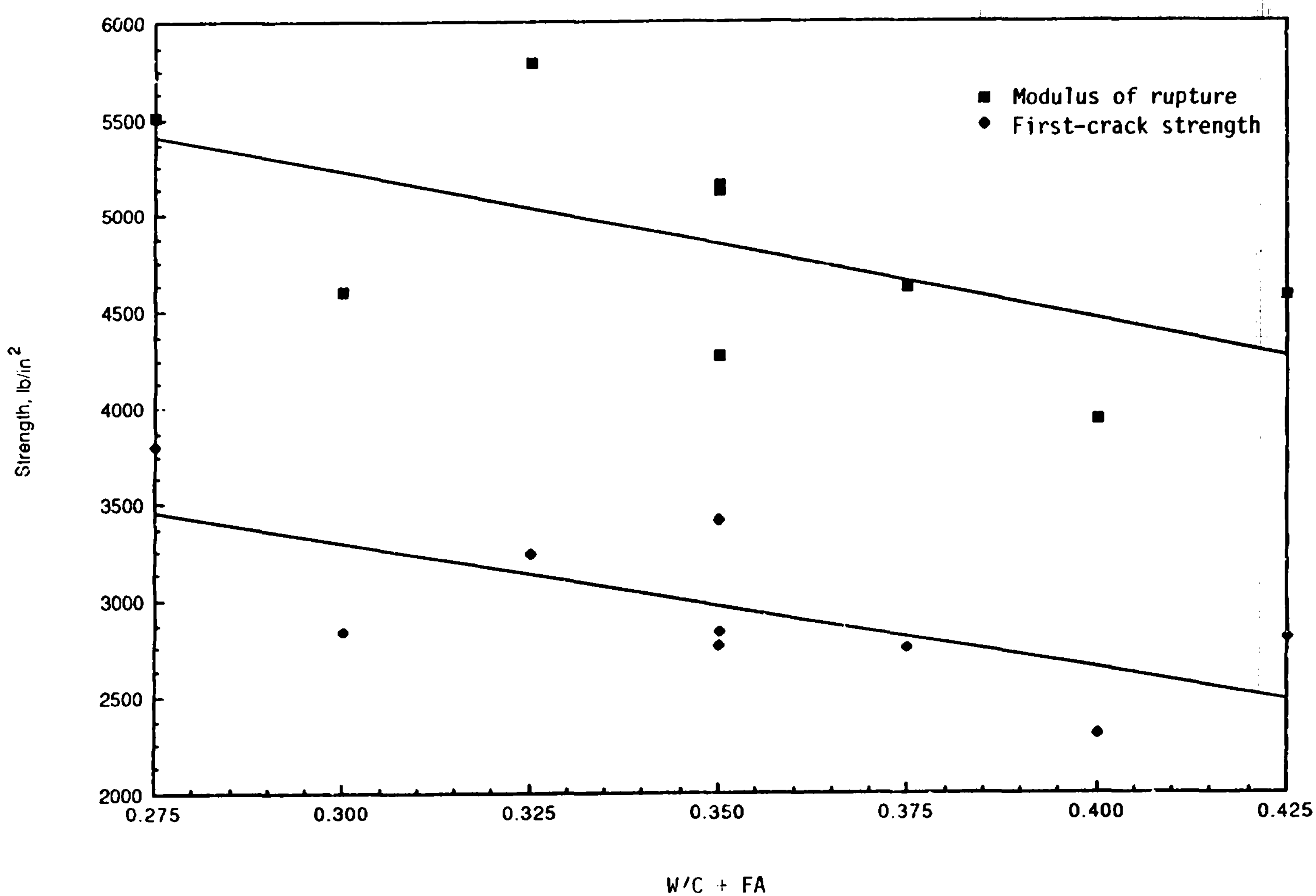


Figure 22. Modulus of rupture and first-crack strength versus water/(cement + fly ash).

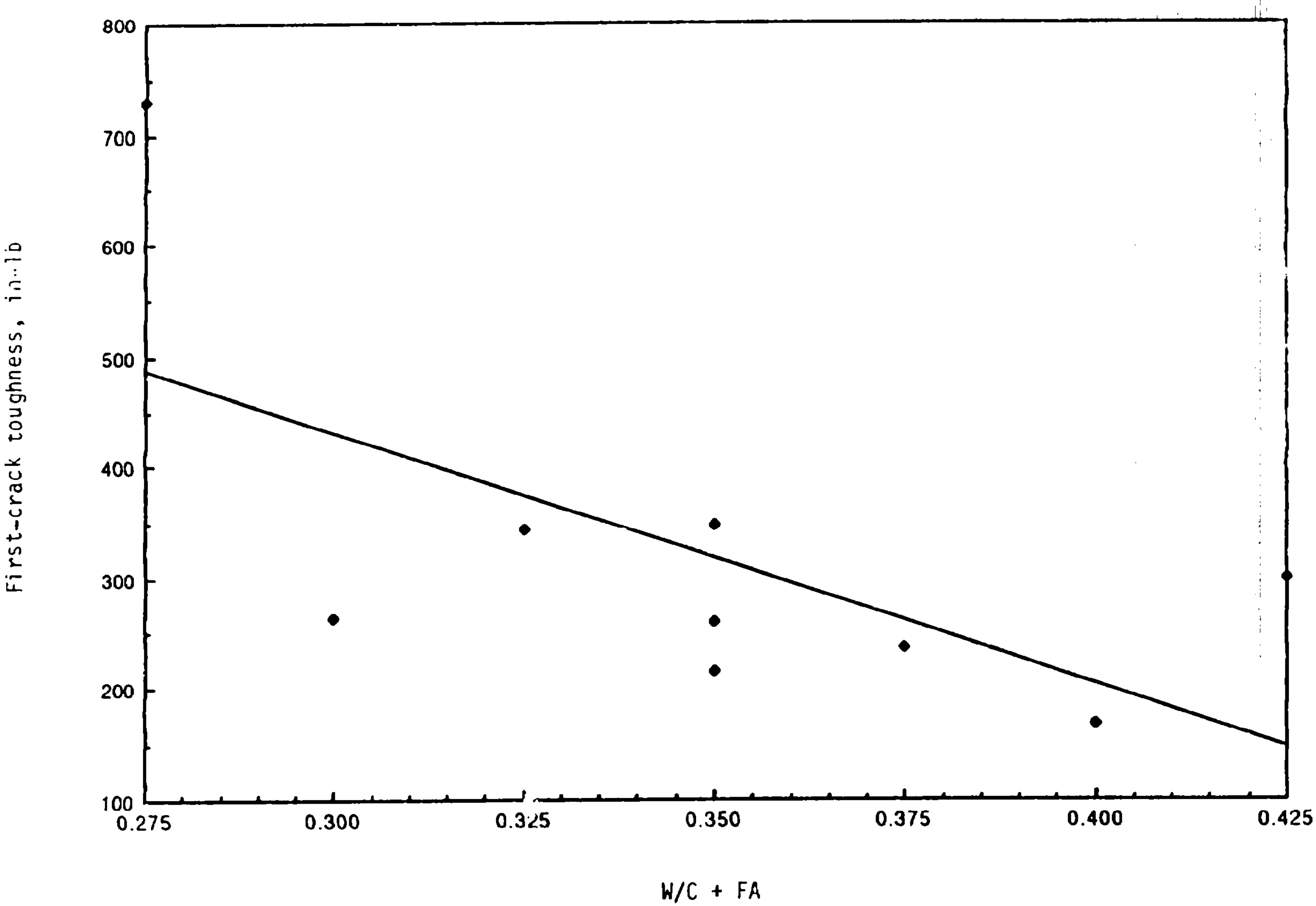


Figure 23. First-crack toughness versus water/(cement + fly ash).

against W/C + FA are presented in Figure 24. The three indexes parallel each other. They each show a slight tendency to increase as the W/C + FA increases.

The range of these indexes from the simple linear regression curve fit includes 3.8 to 6.9 for I_5, 8.9 to 14.8 for I_{10}, and 18.5 to 25.2 for I_{30} over a W/C + FA ratio range of 0.275 to 0.425, respectively. The related I_{10}/I_5 and I_{30}/I_{10} toughness ratios are plotted in Figure 25. These ratios show considerable scatter. If there is any tendency, it is that of decreasing values with an increase in the W/C + FA ratio for these two toughness ratios.

In general, for all parameters there is a decrease in strength for a corresponding increase in the W/C + FA ratio. This is expected of cementitious materials.

Study Group 2--Fly ash versus cement

General--This study group was designed to investigate the effects on SIFCON flexural strength of varying the fly ash-to-cement proportion. All other mix proportions were kept constant. Table A2 contains all mix designs for this study group.

There are three subgroups included in this study group. The subgroups 2a and 2c vary FA/C + FA at constant 0.30 and 0.40 W/C + FA ratios respectively. Subgroup 2b includes identical mix designs used for special studies. All these mixes had a W/C + FA ratio of 0.35 and a FA/C + FA percent of 30.

The major consideration of this program was to study flexural material properties. Compression specimens were also tested. The purpose of these compression tests was to compare and correlate between this program and the previous compression program.

Fluidity--Fluidity measurements were taken for all mixes. All these data are contained in Table B1. The flow measurements of all three of these subgroups paralleled those of the comparable subgroups of the previous program. Subgroup 2a, with the lower W/C + FA ratio, contained the least

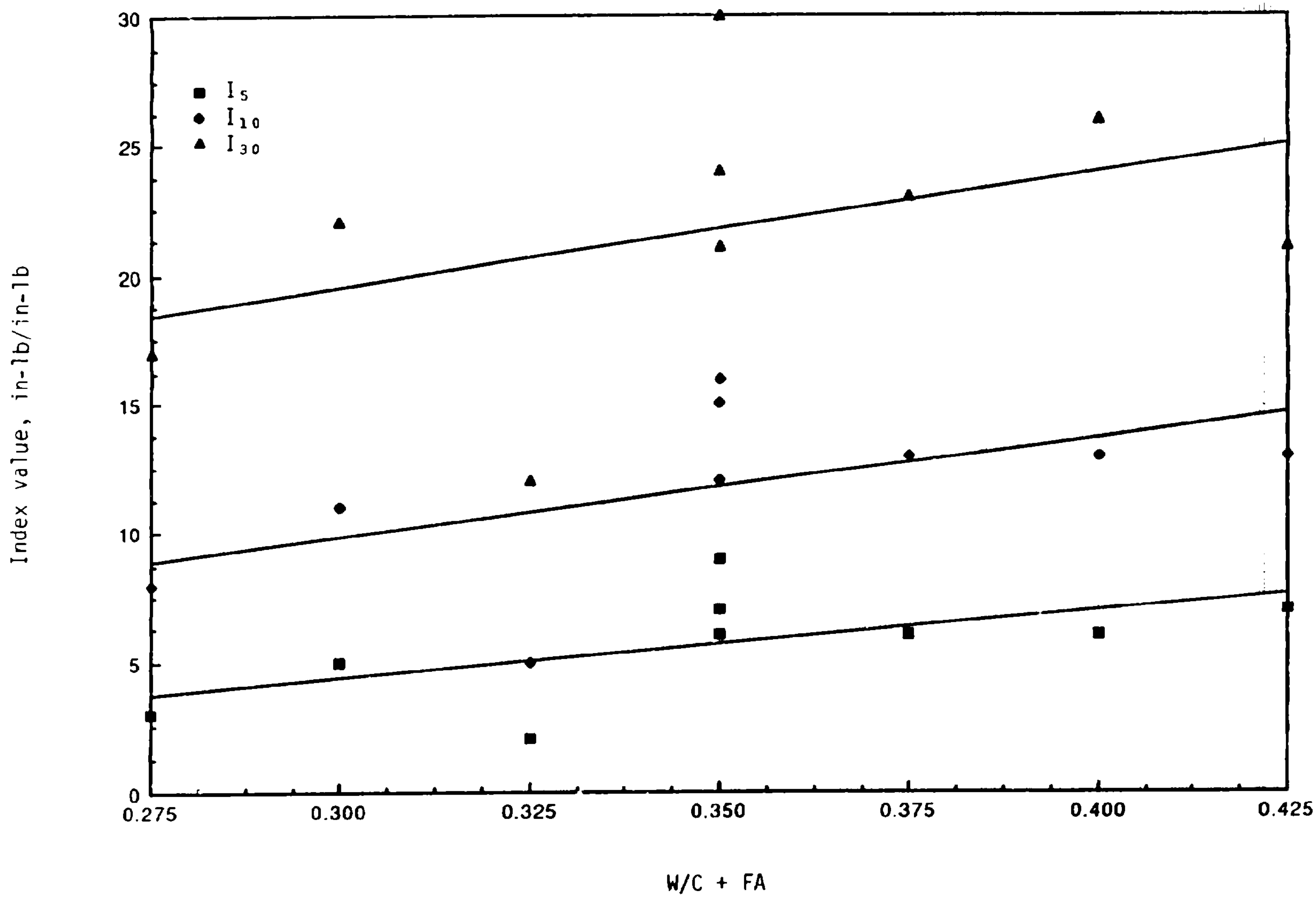


Figure 24. I_5, I_{10}, and I_{30} indexes versus water/(cement + fly ash).

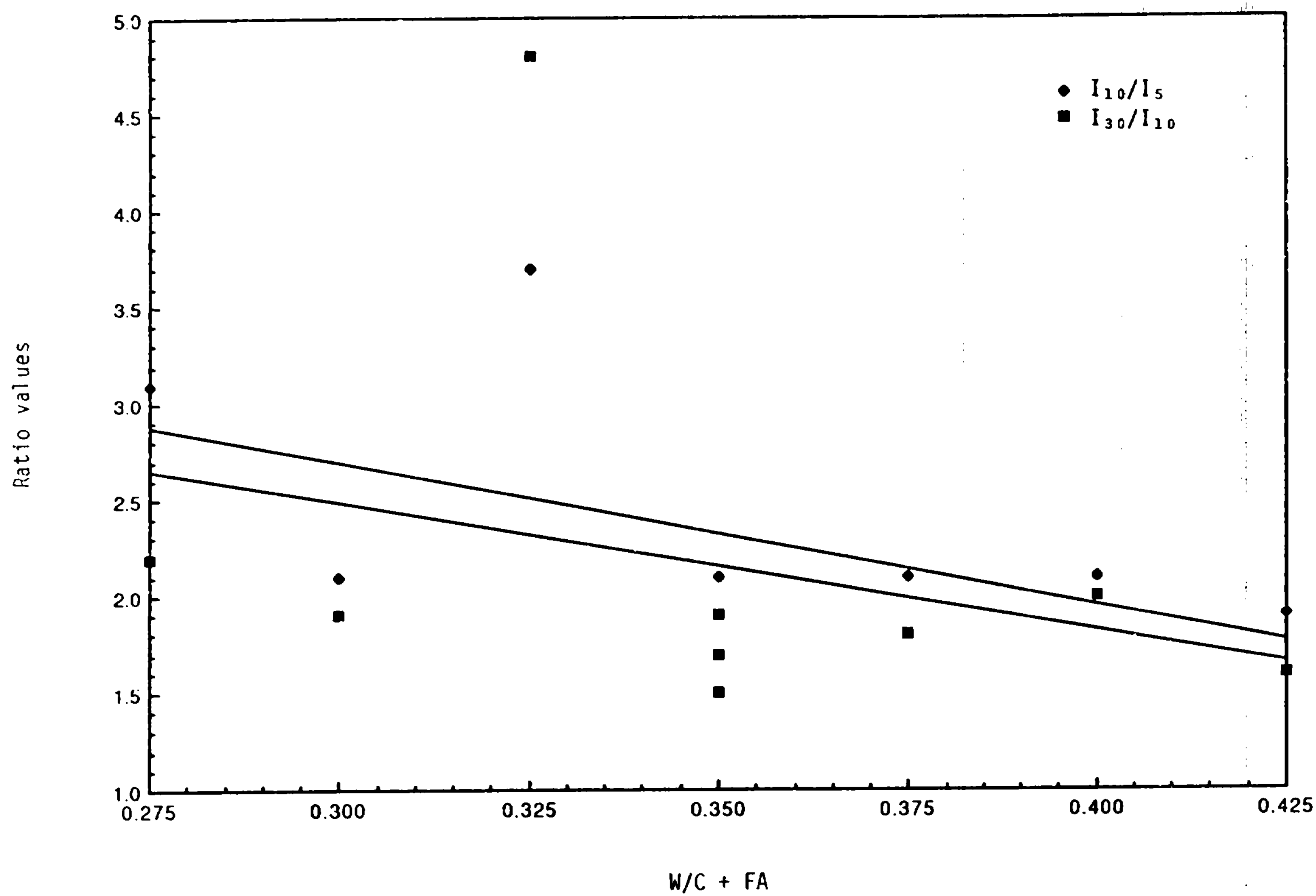


Figure 25. I_{10}/I_5 and I_{30}/I_{10} ratios versus water/(cement + fly ash).

fluid mixes with the lowest open time. Subgroup 2b contained relatively fluid mixes with moderate open times. Even though these were identical mixes, they showed some variation not only in flow measurements but also in open time. Subgroup 2c, with the higher W/C + FA ratios, contained very fluid mixes with relatively long open times. There is a tendency toward greater fluidity with mixes of lower FA/C + FA percentages with the same W/C + FA ratios. This was observed in both subgroups 2a and 2c.

Compression--Specimens were prepared to be tested in compression from all mixes in this study group. Figures F1 and F3 show the range of SIFCON and slurry ultimate strengths obtained for subgroups 2a and 2c, respectively. In general, the lower the FA/C + FA percent, the higher the compression strength. This trend was observed in both the slurry and SIFCON strengths at both the constant low and constant high W/C + FA ratios. These ultimate strength trends are representative of all the other strength values taken from the stress/strain curves. All these other values are contained in Table D2.

The plots in Figures F1 and F3 can be superimposed upon one another, producing Figure 26. This figure shows how closely the individual curves parallel each other. The figure also establishes the practical strength limits for the mix designs of this program.

Figures F2 and F4 compare the compression tests of this program for subgroups 2a and 2c, respectively, with those of the previous program. Again, the repeatability was not as good as expected. The SIFCON ultimate strengths of comparable mixes were consistently lower in this program. Again, the slurry strengths were consistent with the previous slurry strengths. Refer to Study Group 7 discussion for an explanation.

Subgroup 2b served at least two major purposes. First, these mixes were used as the basis of the special studies that are treated under the applicable study groups. Second, it serves to demonstrate the range that can be expected in repeatability. Table 2 contains all the repeated mixes along with averages.

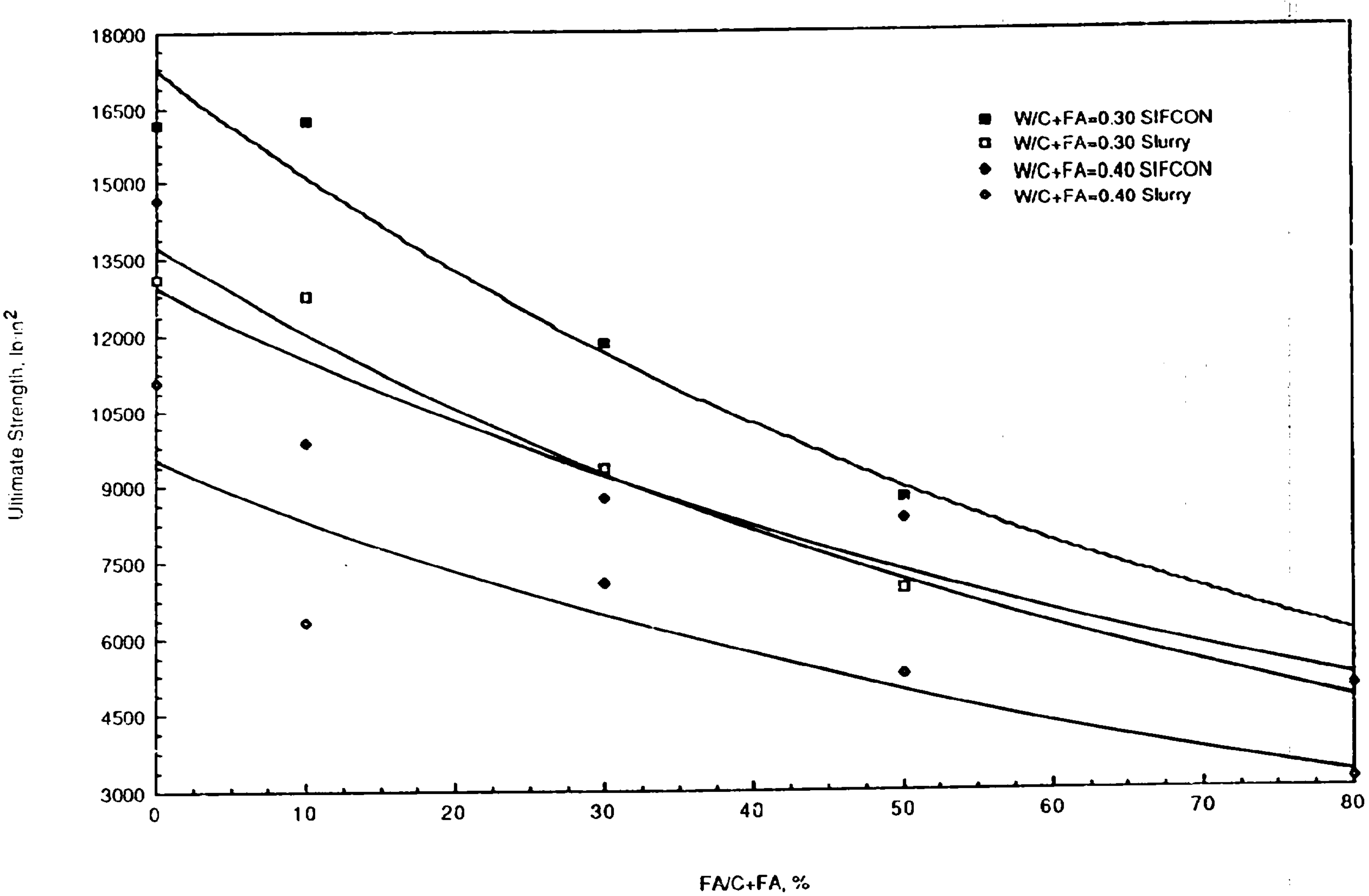


Figure 26. Ultimate compressive strength versus fly ash/cement limits.

TABLE 2. RESULT REPEATABILITY SUMMARY

Study Group 2--Fly ash / cement

Subgroup 2b (W/C+FA = 0.35)

Mix identification code	Ultimate strength		
	SIFCON	Slurry	
	Stress D, lb/in ^{2}	30-Day stress, lb/in ^{2}	7-Day stress, lb/in ^{2}
FAC 35-30 C	12,773	7,360	5567
FAC 35-30 D	9,452	6,950	6340
FAC 35-30 E (typ)	13,613	6,862	
FAC 35-30 F	13430	8,109	5569
FAC 35-30 S	10,434	8,427	6534
FAC 35-30 T	10,253	8,780	6410
Z3/5-35-30 F	10,353	7,004	
Minimum	9,452	6862	5567
Maximum	13,613	8780	6534
Average	11,473	7642	6084

Study Group 3--Fiber types

Mix identification code	Slurry ultimate strength	
	30-Day stress, lb/in ^{2}	7-Day stress, lb/in ^{2}
Z3/4-35-30 F	7098	4940
Z3/5-35-30 F	7004	
FAC 35-30 C	7360	5567
FAC 35-30 D	6950	6340
FAC 35-30 E (typ)	6862	
FAC 35-30 F	8109	5569
FAC 35-30 S	8427	6534
FAC 35-30 T	8780	6410
Z5/5-35-30 F	5509	4974
Z6/8-35-30 F	8081	6423
X12-35-30 F	8503	6229
Minimum	5509	4940
Maximum	8780	6534
Average	7517	5837

Study Group 4--Sand

Mix identification code	Slurry ultimate strength	
	30-Day stress, lb/in ^{2}	7-Day stress, lb/in ^{2}
S1-0-35-30	8226	5471
S2-0-35-30	7539	5166
S3-0-35-30	8203	5498
S4-0-35-30	6682	5385
S5-0-35-30	8613	5511
Minimum	6682	5166
Maximum	8613	5511
Average	7853	5406

All repeated mixes

Mix identification code	Ultimate strength		
	SIFCON	Slurry	
	Stress D, lb/in ^{2}	30-Day stress, lb/in ^{2}	7-Day stress, lb/in ^{2}
Minimum	9,452	5509	4940
Maximum	13,613	8780	6534
Average	11,473	7622	5716
Variation, %	30.57	37.26	24.40

From the seven identical mixes of subgroup 2b produced at different times, a wide range of not only SIFCON but also slurry strengths was obtained. The range of 30-day strengths obtained varied between 9452 to 13,613 lb/in^2 (a variation of 30.57 percent) for SIFCON and 6862 to 8780 lb/in^2 (a variation 21.85 percent) for the respective slurries. This variation value was calculated by taking the percent of the difference between the minimum and maximum values divided by the maximum. The average values calculate to 11,473 lb/in^2 for SIFCON and 7642 lb/in^2 for the slurries. One might expect better repeatability. There are at least a few observed reasons contributing to the high and low SIFCON values. The low value represented specimens with the highest height/diameter ratio of the program with an average of 2.241. The corresponding slurry strength was also relatively low. These reasons account for only a part of the explanation for the low value. The high SIFCON value also represented unusual specimens. The height/diameter ratio was low at an average of 1.827. Again, this accounts for only part of the reason for a high value. If one were to omit the high and low SIFCON values, the average would change only negligibly (11,499 lb/in^2). However, the variation would drop to 23.66 percent. Note also that the average of the SIFCON tests of this program (11,473 lb/in^2) was lower than that of the corresponding SIFCON average of the previous program (12,735 lb/in^2). Other possible reasons for this discrepancy are discussed in the treatment of Study Group 7. The slurry, however, was only slightly higher at 7642 lb/in^2 than that of the previous program at 7595 lb/in^2 for the comparable subgroup. The same slurry proportions were also used in the fiber-type study group and some of the sand mixes. These are also contained in Table 2. The average of all the combined identical mixes of 7622 lb/in^2 was lower than the average of all the combined comparable slurries of the previous program (7926 lb/in^2).

In conclusion, it seems that one can expect quite a range of variability in SIFCON strength results using the same procedures and the same mix proportions.

Flexure--The same flexure parameters as those studied in Study Group 1 were compared in this study group. The results are tabulated in Table D2.

Figures 27 and 28 present the strength comparisons of both the modulus of rupture and first-crack strength for subgroups 2a and 2c. Both sets of curves demonstrate a lowering of strength with an increase in FA/C + FA percentage. This was expected, since a higher cement content should give higher strengths. For the two sets of exponential regression curve fits of the data, the modulus of rupture values ranged from 5350 to 4400 lb/in^2 for subgroup 2a and 5650 to 2250 lb/in^2 for subgroup 2c over a FA/C + FA range of 0 to 50 percent, respectively. The sets of first-crack strengths show similar trends but with a slower decline in strength than the modulus of rupture. All four curves were plotted using an exponential regression curve fit. The two curves in Figure 27, however, turned out very flat, appearing linear. The exponential regression curve fit for the first crack strengths ranged from strengths of 2650 to 2350 lb/in^2 for subgroup 2a and 3200 to 1400 lb/in^2 for subgroup 2c over the same range of FA/C + FA percentages.

The plots for modulus of rupture in Figures 27 and 28 can be superimposed upon one another, producing Figure 29. The figure establishes the approximate modulus of rupture limits for the mixes of this program.

Figures 30 and 31 present the flexure modulus of elasticity for the SIFCON in subgroups 2a and 2c. In both curves there is a lowering of the modulus of elasticity as the FA/C + FA percentage increases. Again, an exponential regression curve fit was used for both. Figure 30 also turned out flat. The curve fit for the two curves ranged from values of 590 to 402 k/in^2 for subgroup 2b over a FA/C + FA percentage of 0 to 50, and 620 to 195 k/in^2 for subgroup 2c over a FA/C + FA percentage of 0 to 80.

The same SIFCON toughness parameters as those of Study Group 1 were compared for this study group also. The comparisons of first crack toughness are presented in Figures 32 and 33 for subgroups 2a and 2c. The data of the first-crack toughness for subgroup 2a were too scattered to reveal any trends. The same plot for subgroup 2c showed a lowering of toughness with an increase in FA/C + FA percent. From the exponential regression curve fit, the first-crack toughness ranged from 223 to 150 in-lb for a FA/C + FA percent of 0 to 80 for subgroup 2c. The plots of I_5, I_{10}, and I_{30} toughness indexes against FA/C + FA are presented in Figures 34 and 35 for subgroups 2a and 2c, respectively. The three curves of subgroup 2a each

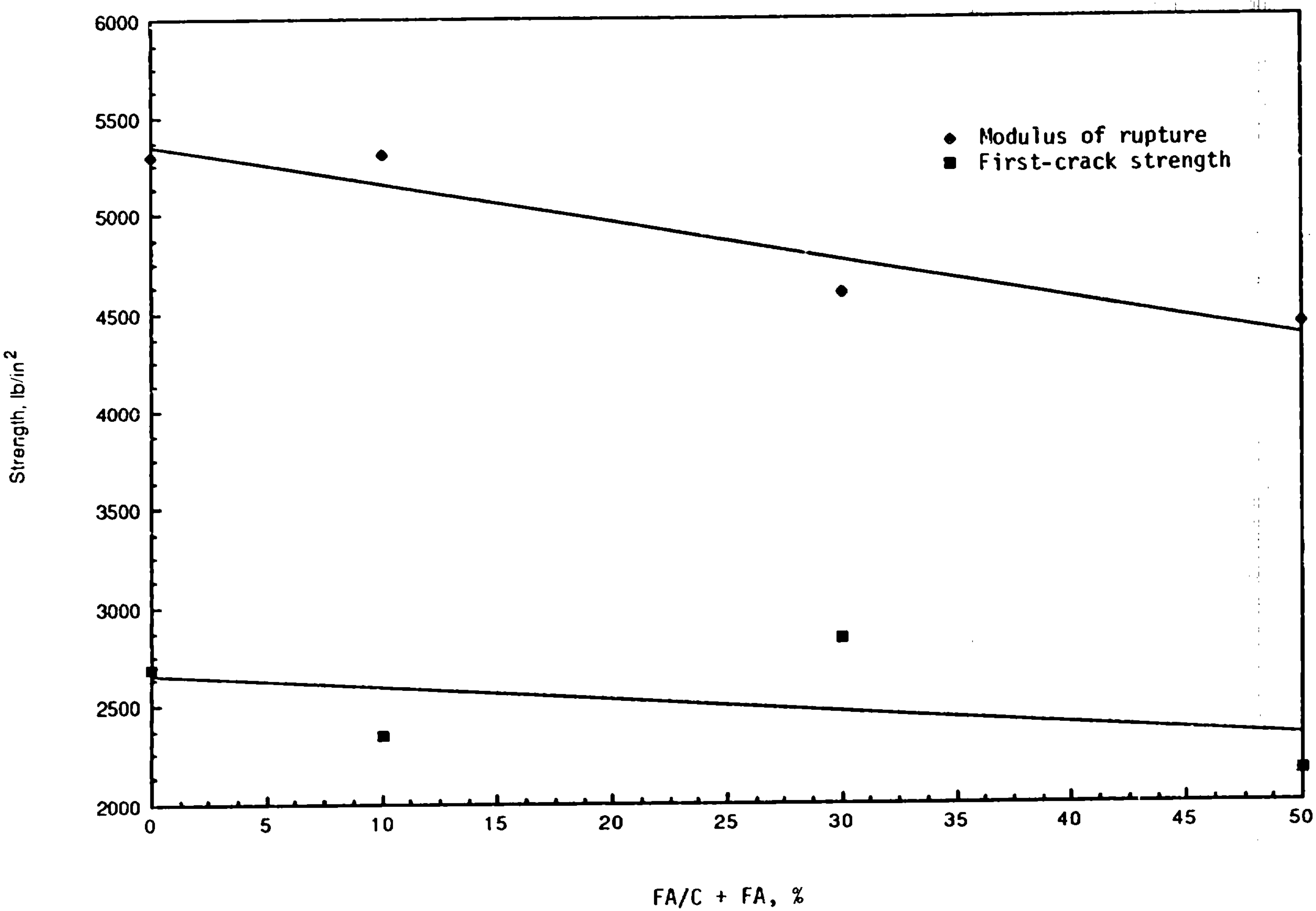


Figure 27. Modulus of rupture and first-crack strength versus fly ash/cement (W/C + FA = 0.30).

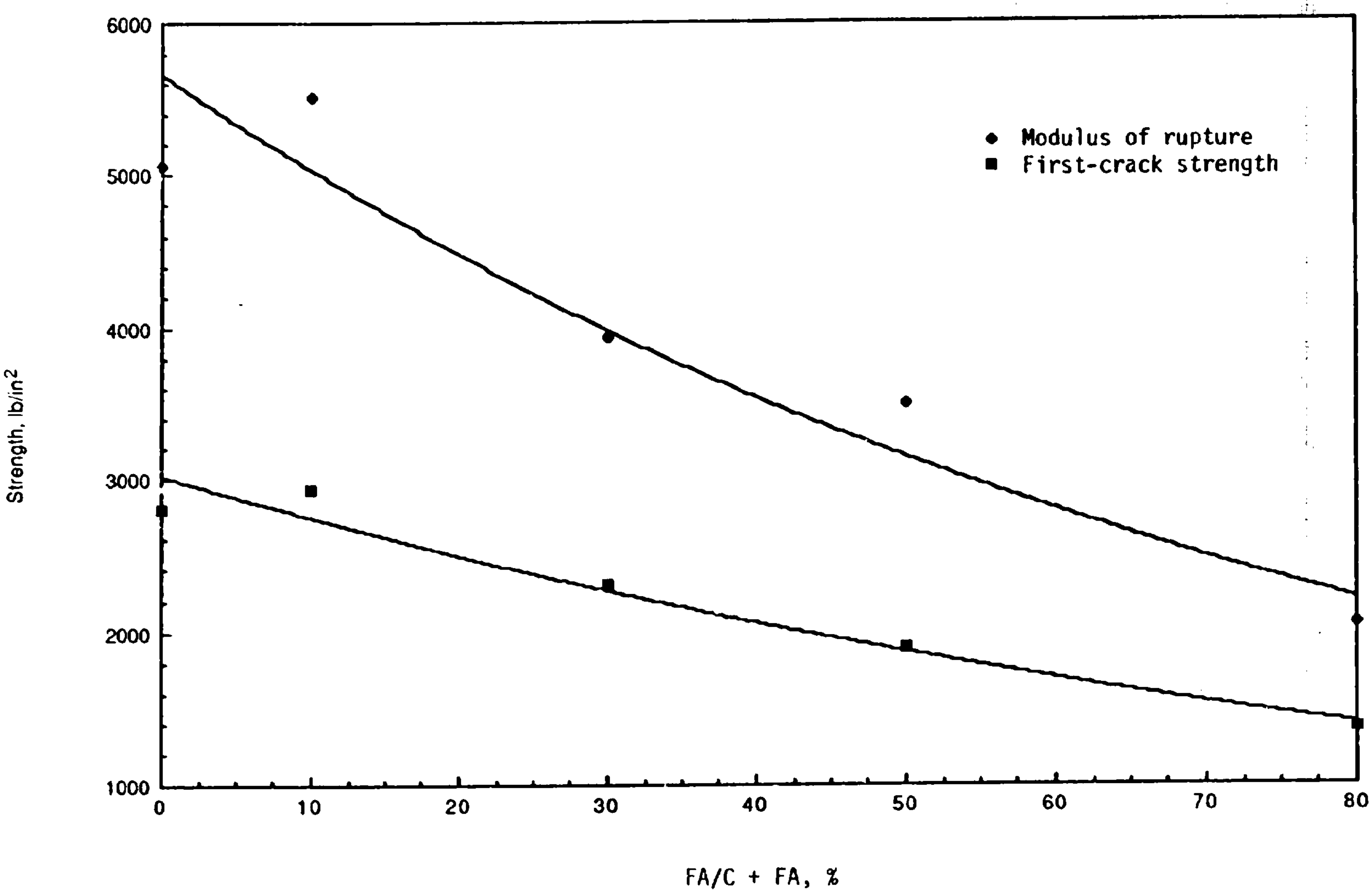


Figure 28. Modulus of rupture and first-crack strength versus fly ash/cement (W/C + FA = 0.40).

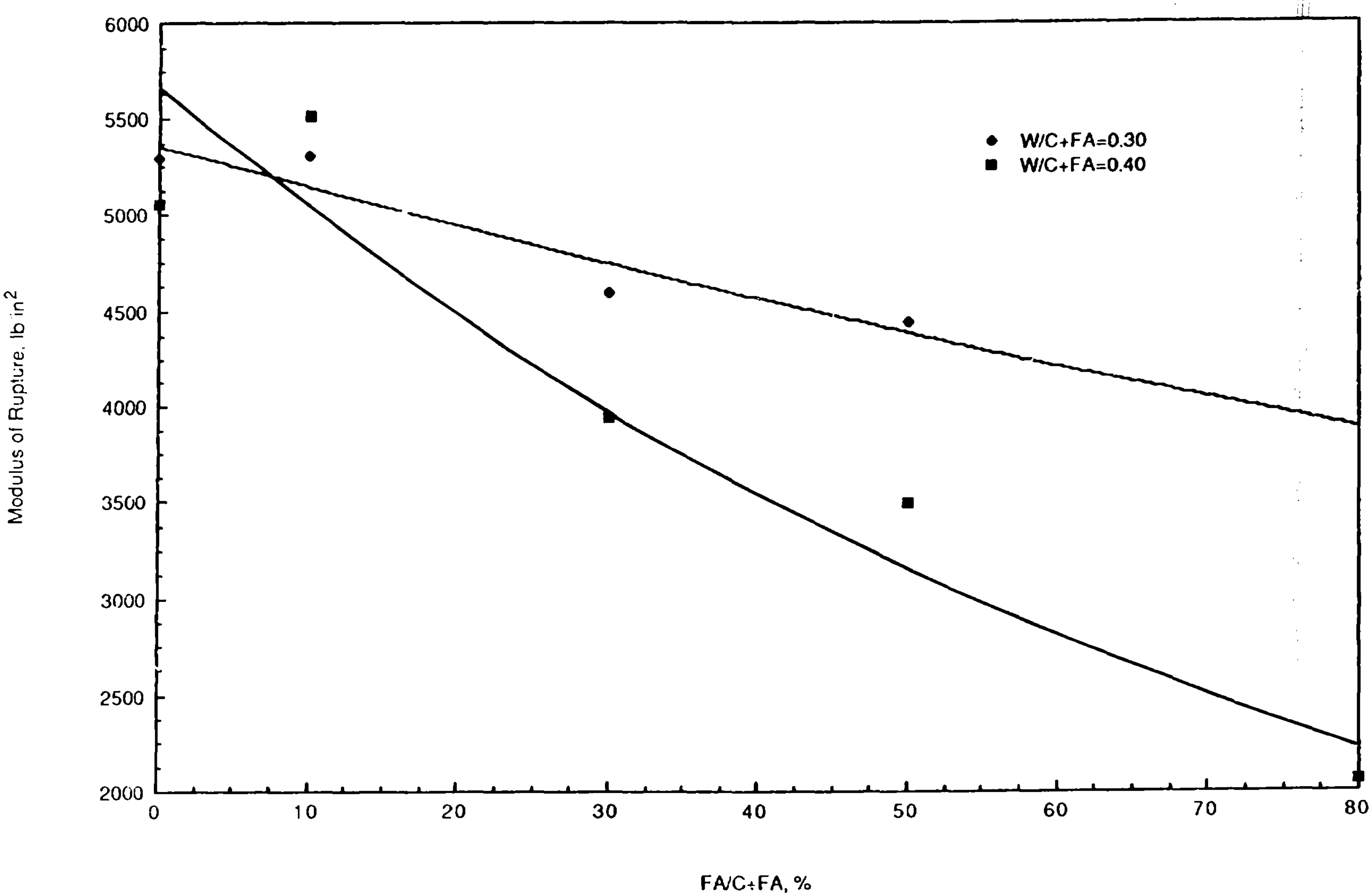


Figure 29. Modulus of rupture versus fly ash/cement limits.

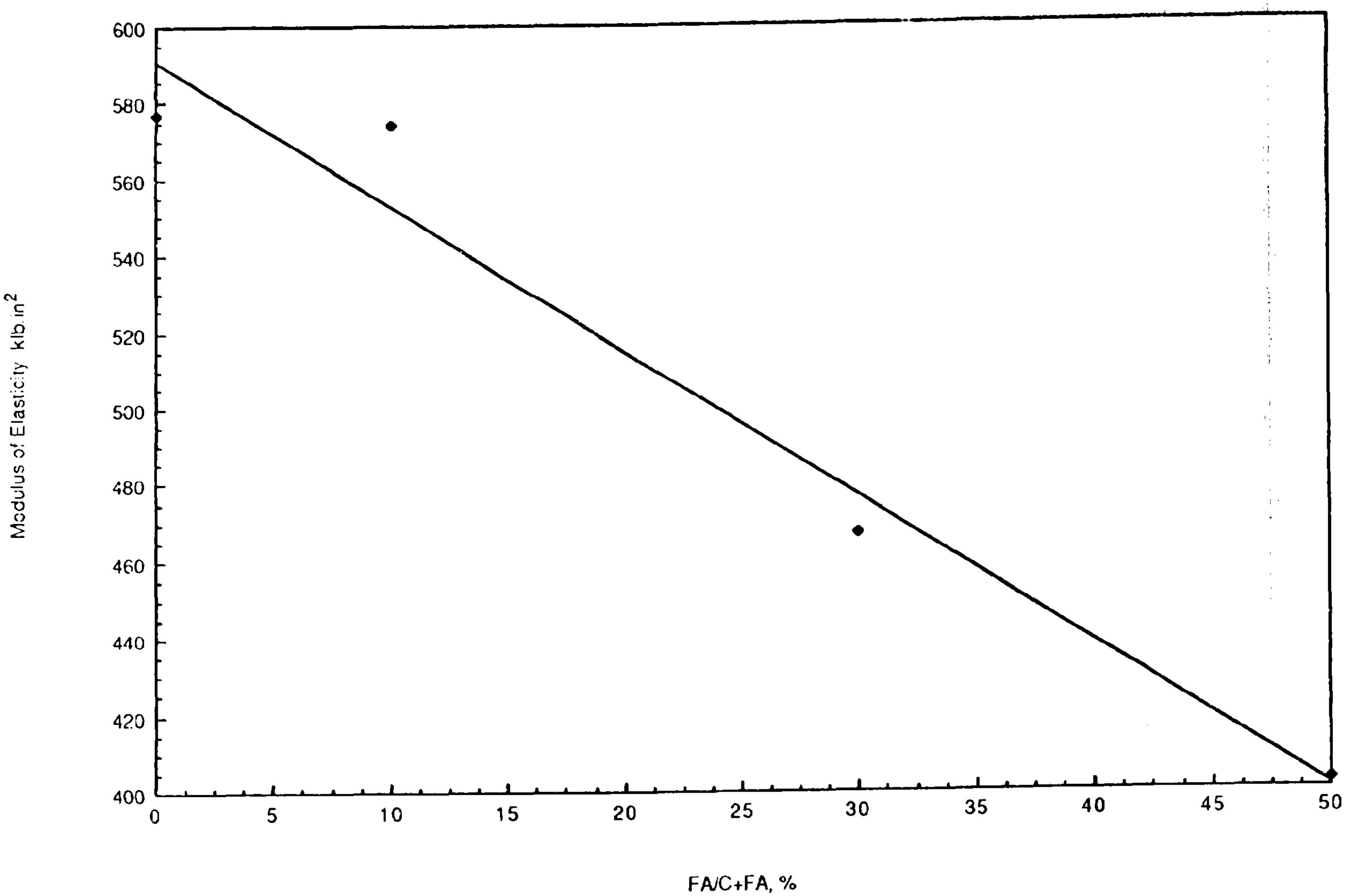


Figure 30. Flexure modulus of elasticity versus fly ash/cement (W/C + FA = 0.30).

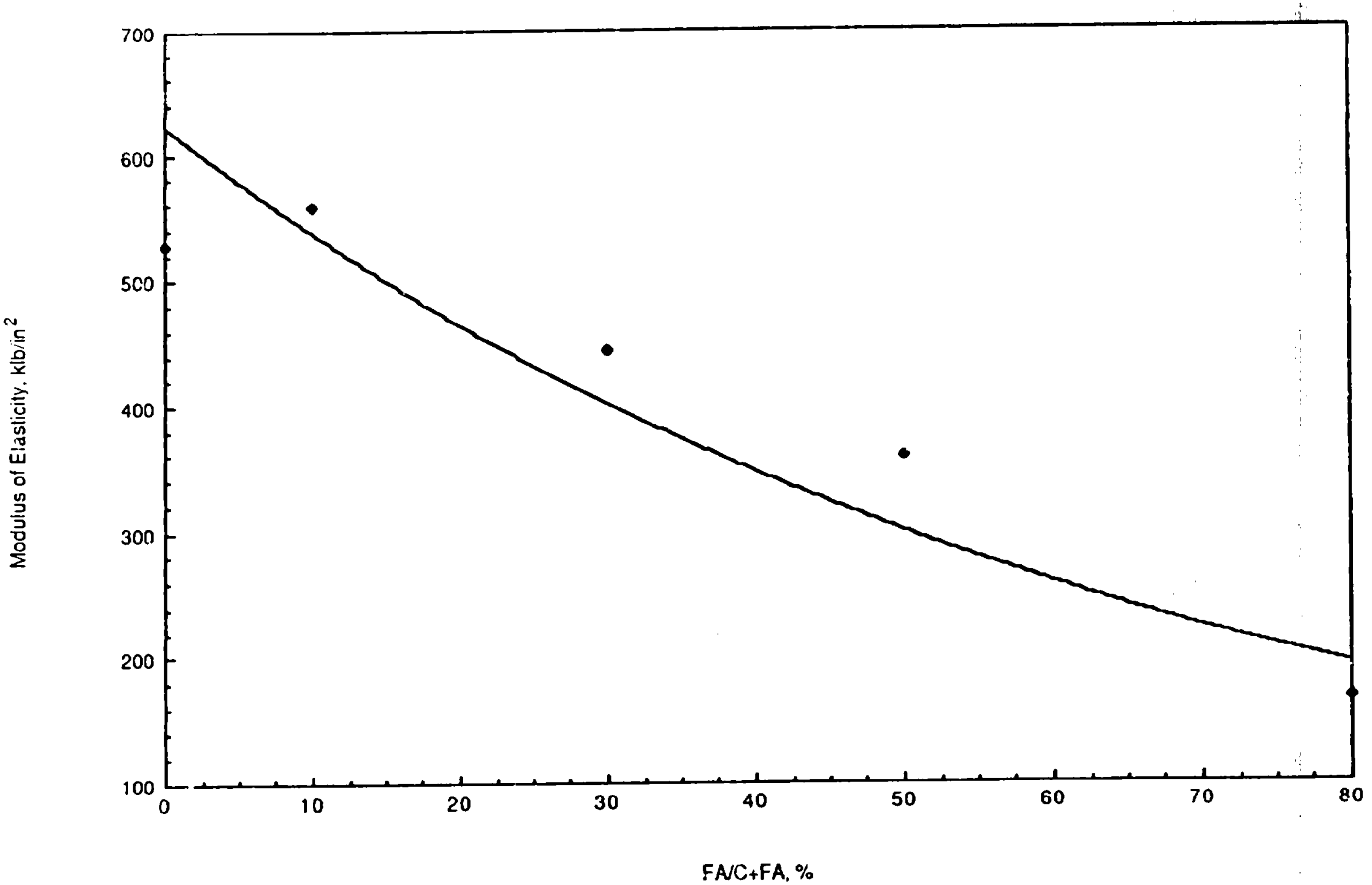


Figure 31. Flexure modulus of elasticity versus fly ash/cement (W/C + FA = 0.40).

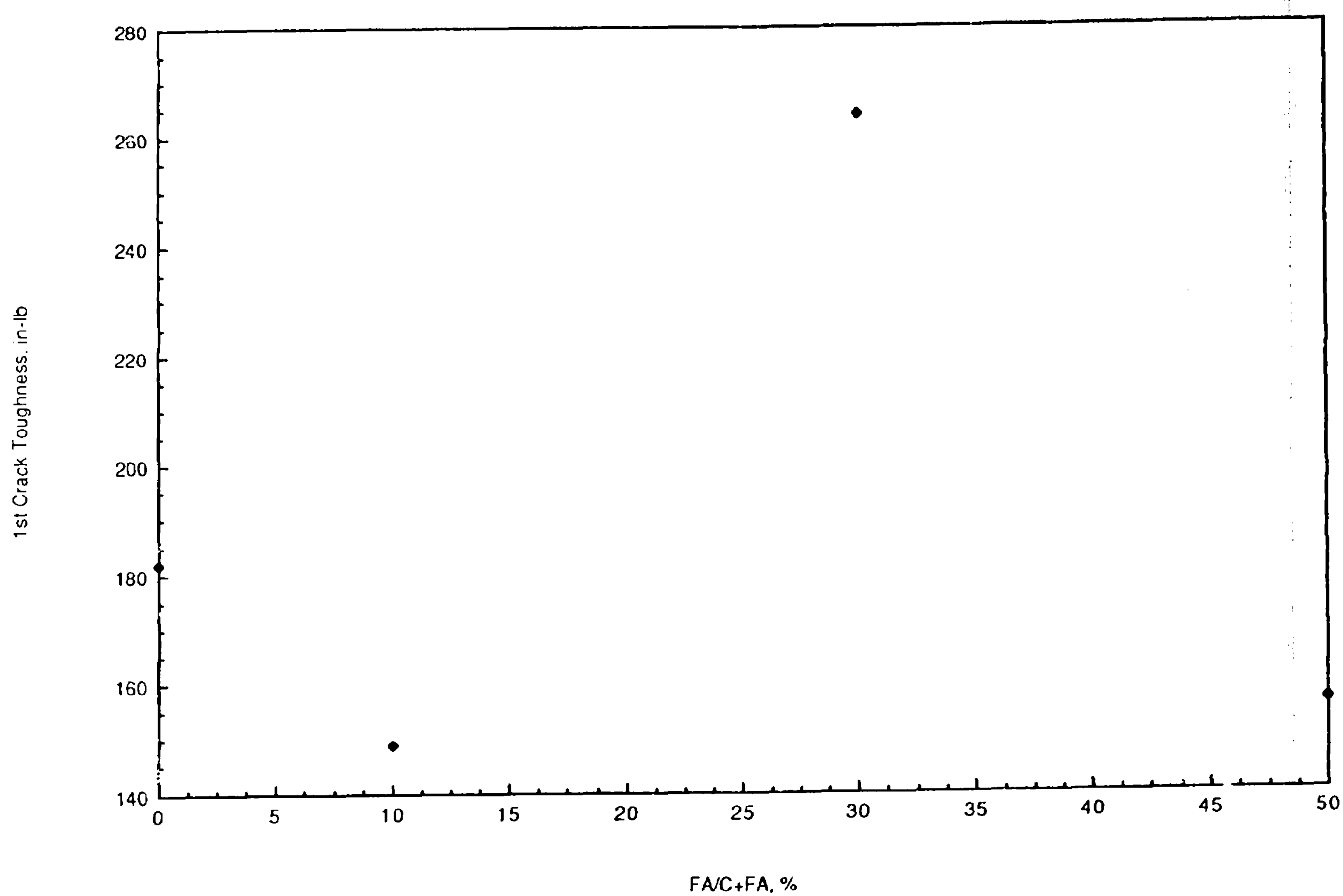


Figure 32. First-crack toughness versus fly ash/cement (W/C + FA = 0.30).

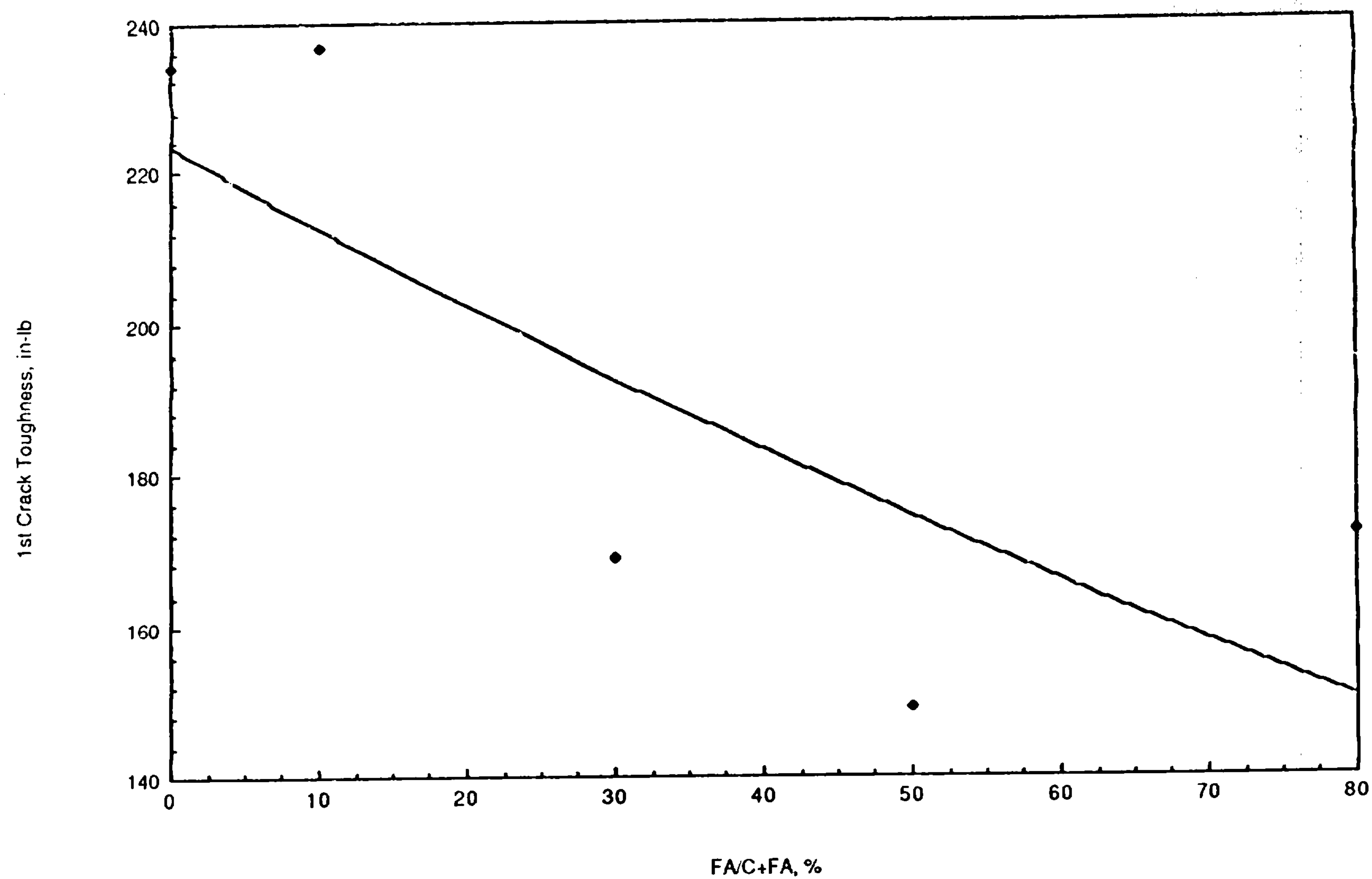


Figure 33. First-crack toughness versus fly ash/cement (W/C + FA = 0.40).

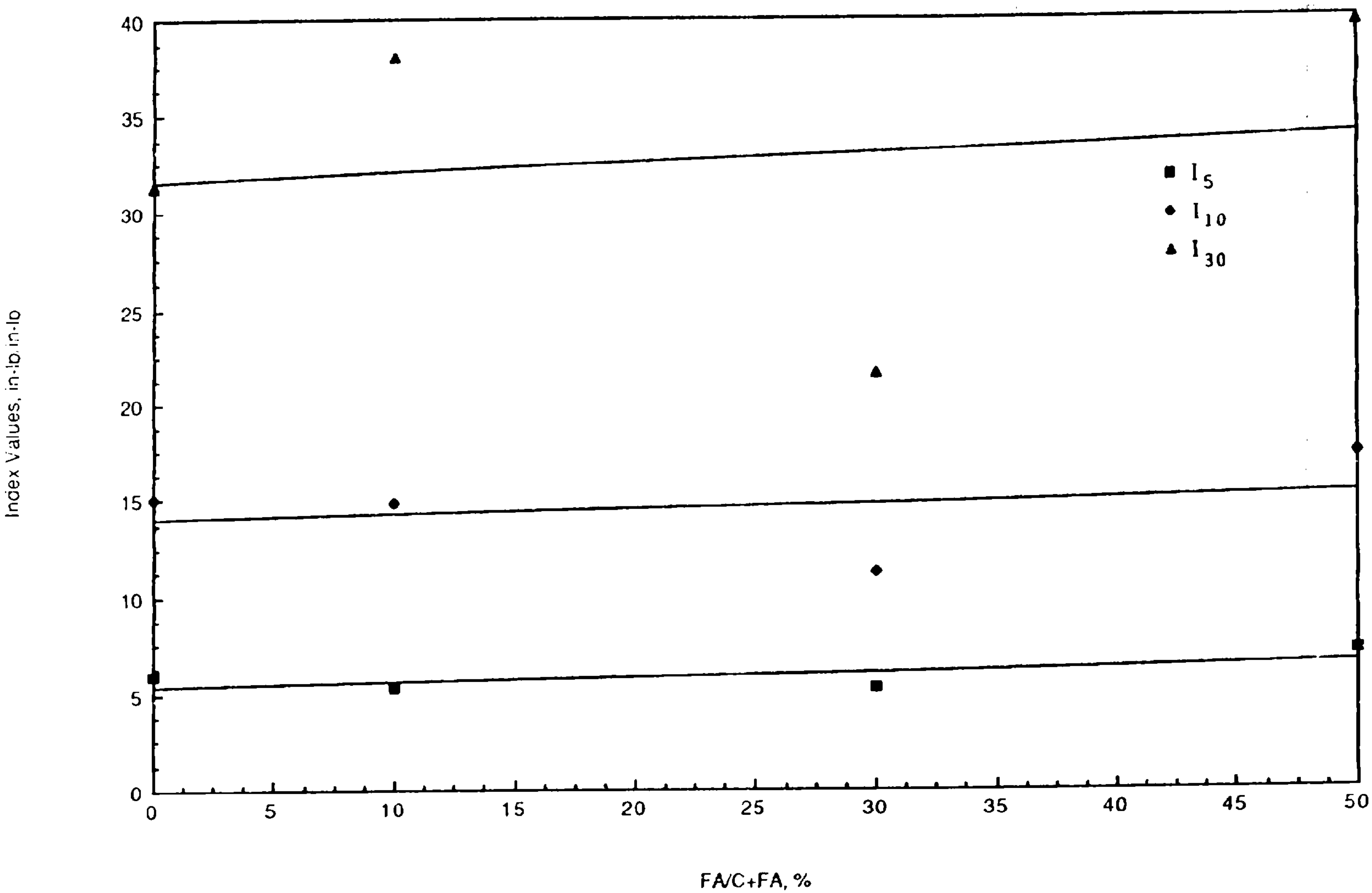


Figure 34. I_5, I_{10}, and I_{30} indexes versus fly ash/cement (W/C + FA = 0.30).

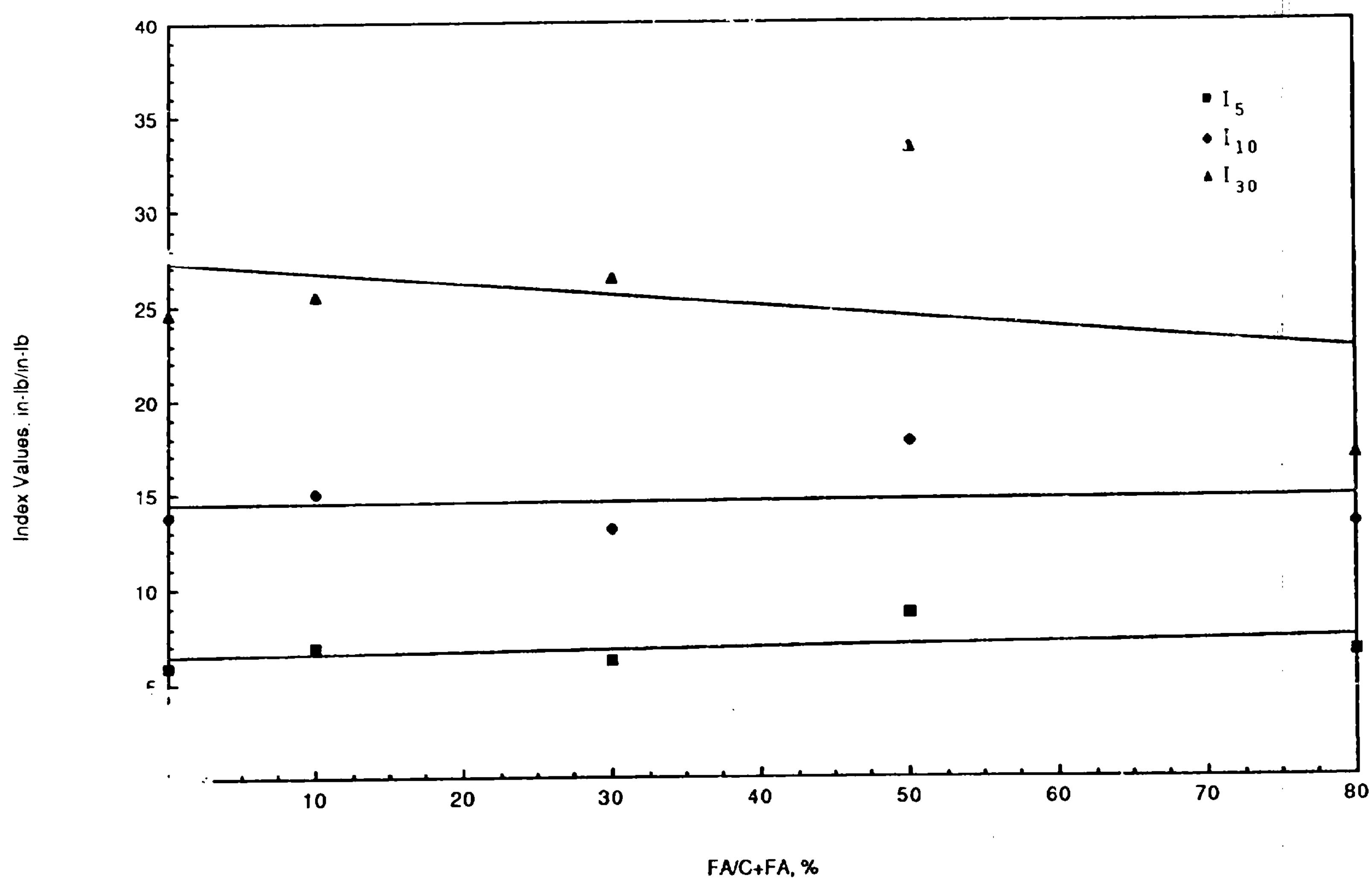


Figure 35. I_5, I_{10}, and I_{30} indexes versus fly ash/cement (W/C + FA = 0.40).

seem to increase linearly very slightly with an increase in FA/C + FA percentage. The range of these indexes from the simple linear regression curve fits includes 5.6 to 6.1 for I_5, 13.2 to 15.3 for I_{10}, and 31.0 to 33.3 for I_{30} over an FA/C + FA percentage range of 0 to 50, respectively. The I_5 and I_{10} toughness index curves of subgroup 2c seem to increase linearly very slightly, but the I_{30} curve decreases linearly with an increase in FA/C + FA percentages. The range of these indexes from the simple linear regression curve fits includes 6.3 to 7.2 for I_5, 14.4 to 14.6 for I_{10}, and 27.2 to 22.2 for I_{30} over a FA/C + FA percentage range of 0 to 80, respectively. The related I_{10}/I_5 and I_{30}/I_{10} toughness ratios are plotted in Figures 36 and 37 for subgroups 2a and 2c, respectively. The tendency of the values seems to be a decrease with an increase in the FA/C + FA percentage for both sets of toughness ratios.

In general, for all parameters there is a decrease in strength for a corresponding increase in the FA/C + FA percentage. This is expected of cementitious materials.

Study Group 3--Fiber types

General--This study group was designed to investigate the effects on flexural strength of varying different types of fibers. All other mix proportions were kept constant. Table A3 contains all mix designs for this study group.

The major consideration of this program was to study flexural material properties. Compression specimens were also tested. The purpose of these compression tests was to compare this program to the previous compression program and correlate the results.

Fluidity--Fluidity measurements were taken for all mixes. All these data are contained in Table B1. Since the slurries of this study group had the identical mix proportions, the fluidity was expected to be similar. There is some variation of both flow measurements and open times. The variation, however, is not inconsistent with that of previous experience. The average initial flow at T = 7 min is 21 s. The average open time is approximately 45 min.

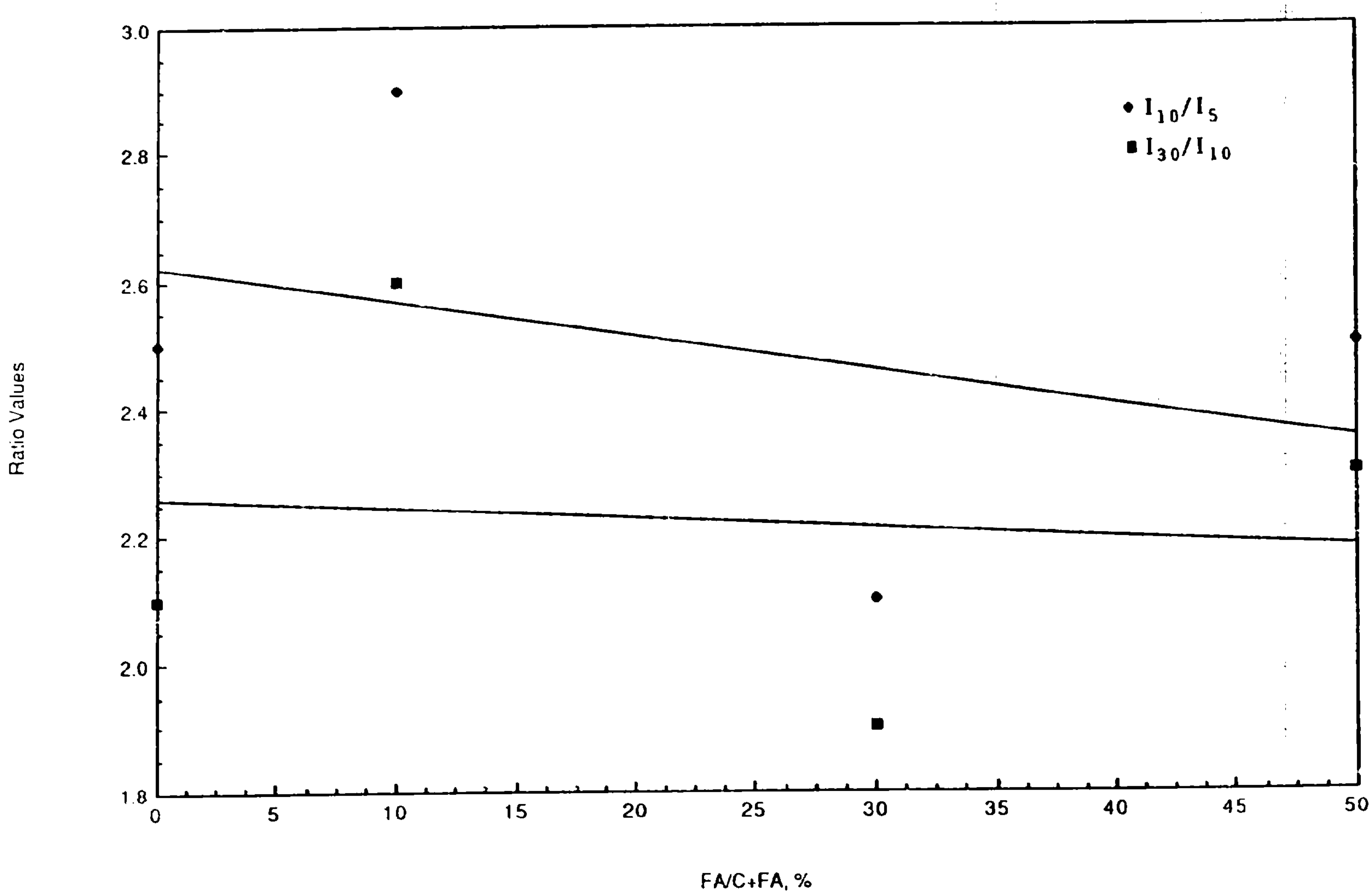


Figure 36. I_{10}/I_5, and I_{30}/I_{10} ratios versus fly ash/cement (W/C + FA = 0.30).

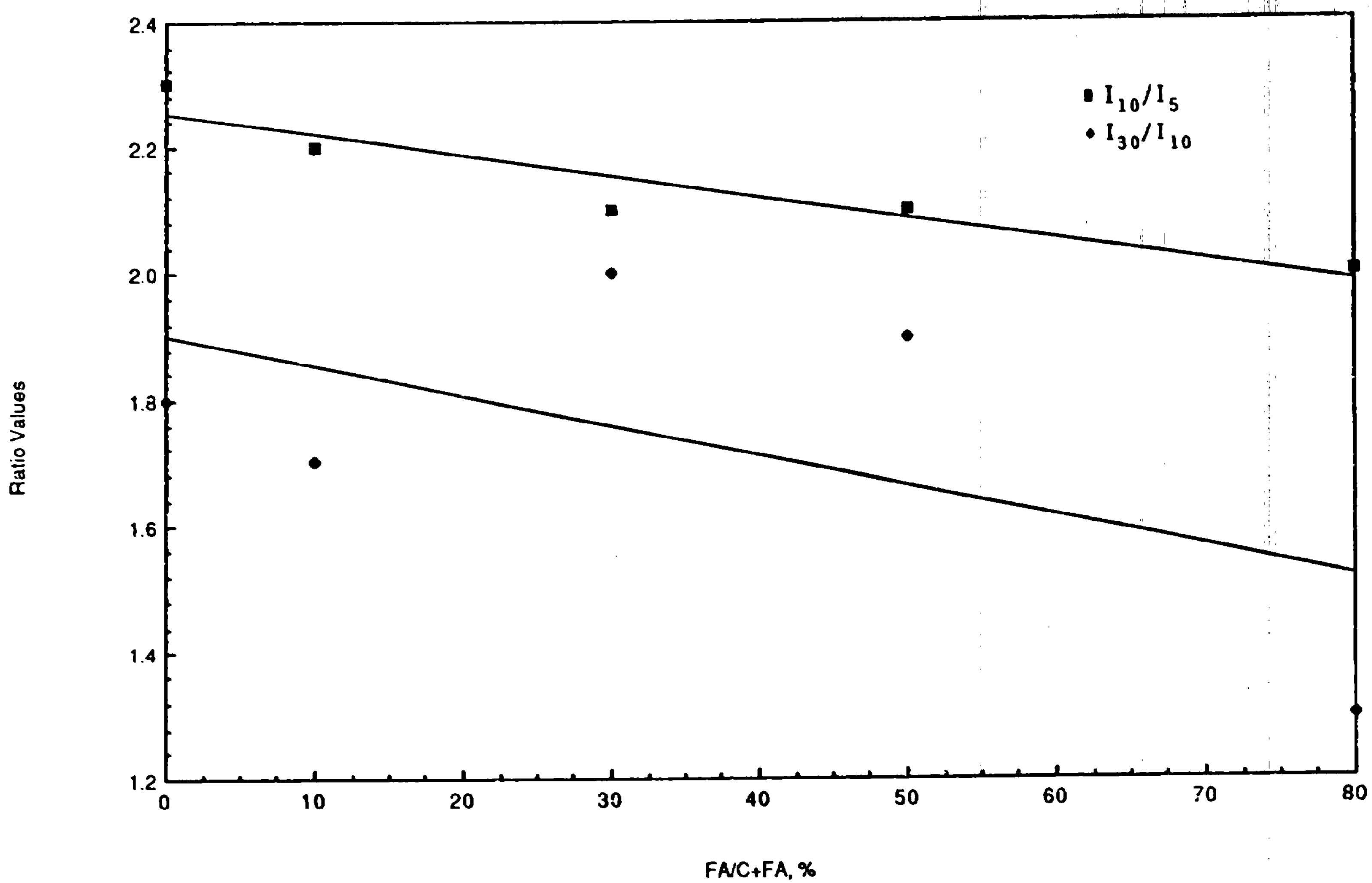


Figure 37. I_{10}/I_5, and I_{30}/I_{10} ratios versus fly ash/cement (W/C + FA = 0.40).

Compression--Specimens were prepared to be tested in compression from all mixes in this study group. Figure G1 shows the range of SIFCON and slurry ultimate strengths obtained for this study group. Table D3 tabulates the compression results. The trends of SIFCON strength versus the fiber types again remains inconclusive. There were too many variables within just the fibers themselves to be conclusive. The various limitations of this comparison were stated in detail in the report of the previous program (Ref. 1, pp. 41-47). The basic limitations include the vast differences between the fiber types, such as shape, length, diameter, aspect ratio, tensile strength, and percentages of loading (refer to Table 1). Figure G1 compares only the fiber types, irrespective of their individual peculiar properties. The fiber strengths are grouped according to the three major fiber types--Dramix, Xorex, and Fibercon. In general, the Dramix ZL 30/50 fibers yielded the higher strengths. The Xorex I/1-in fibers reached a comparable strength. Cores of this Xorex SIFCON broke down, so no cores were obtained. However, saw-cut rectangular shapes were prepared with a 2-to-1, height-to-equivalent-diameter ratio. Because of this, it seems that the coring of 2.75-in-diam cores from some fiber types may not give representative test results. No cores were successfully obtained for these Xorex I/1-in fibers in the previous program either.

Some fibers yielded SIFCON strengths below their corresponding slurry strengths. Reasons for this phenomenon are discussed in detail in the report of the previous program (Ref. 1, pp. 42-47). These fiber types with low strength tend to align predominantly in horizontal planes. It appeared that the coring techniques used were detrimental to these SIFCON specimens, since some failed in the coring process along these horizontal planes. Other reasons are mentioned in the Study Group 7 discussion.

Figure G2 compares the results of this study group with results of the previous program. With some clear exceptions, the results of this program are comparable with those of the previous program. The exceptions include Dramix ZL 60/80, Xorex I/2 1/2-in, and Fibercon fibers. In each of these cases, the SIFCON of this program was lower than that of the previous program.

Flexure--The same flexure parameters as those studied in Study Group 1 were compared in this study group. The results are tabulated in Table D3.

Figure 38 presents the strength comparisons of both the modulus of rupture and first-crack strength for this study group. In general the Dramix SIFCON showed higher strengths for both modulus of rupture and first-crack strength than Xorex or Fibercon. The Fibercon SIFCON strengths were at the lower end of Dramix SIFCON and higher than Xorex. Dramix SIFCON strengths ranged from 5149 for ZL 30/50 to 3307 lb/in^2 for ZL 60/80. Xorex SIFCON strengths ranged from 2605 lb/in^2 for Xorex I/2 1/2-in to 1871 lb/in^2 for Xorex II/1-in. Fibercon SIFCON strength reached 3360 lb/in^2.

Most flexure specimens were molded 4 in deep and 4 in wide according to ASTM C-1018. For long fibers, ASTM C-1018 specifies that the width of beam specimens must be greater than three times the longest fiber length. This required that some specimens (ZL 50/50, ZL 60/80, Xorex I/2 1/2-in, and Xorex II/1 1/2-in) be molded in larger beams. A 6-in by 6-in mold was selected because of availability and practicality. Since ZL 60/80 and Xorex I/2 1/2-in fibers are longer than 2 in, they lie outside the standard. For comparison, the four longer fiber types were molded in 2 sets of specimens. A set of 4- by 4- by 14-in and a set of 6- by 6- by 21-in specimens were molded. The first entry in Figure 38 of the repeated mix identification code is the test results of the smaller beam of the two. Except for the ZL 60/80 SIFCON, the larger specimens yielded a significantly lower modulus of rupture and first crack strength than the smaller ones. The ZL 60/80 SIFCON resulted in test values very close to each other. Perhaps these duplicate test results show a tendency for the larger beam specimens to be more conservative than the smaller sizes for these longer fiber types.

The first-crack toughness and the modulus of elasticity are plotted against fiber types in Figures 39 and 40, respectively. There are no discernible trends except that again the Dramix values exceed the Xorex and Fibercon values.

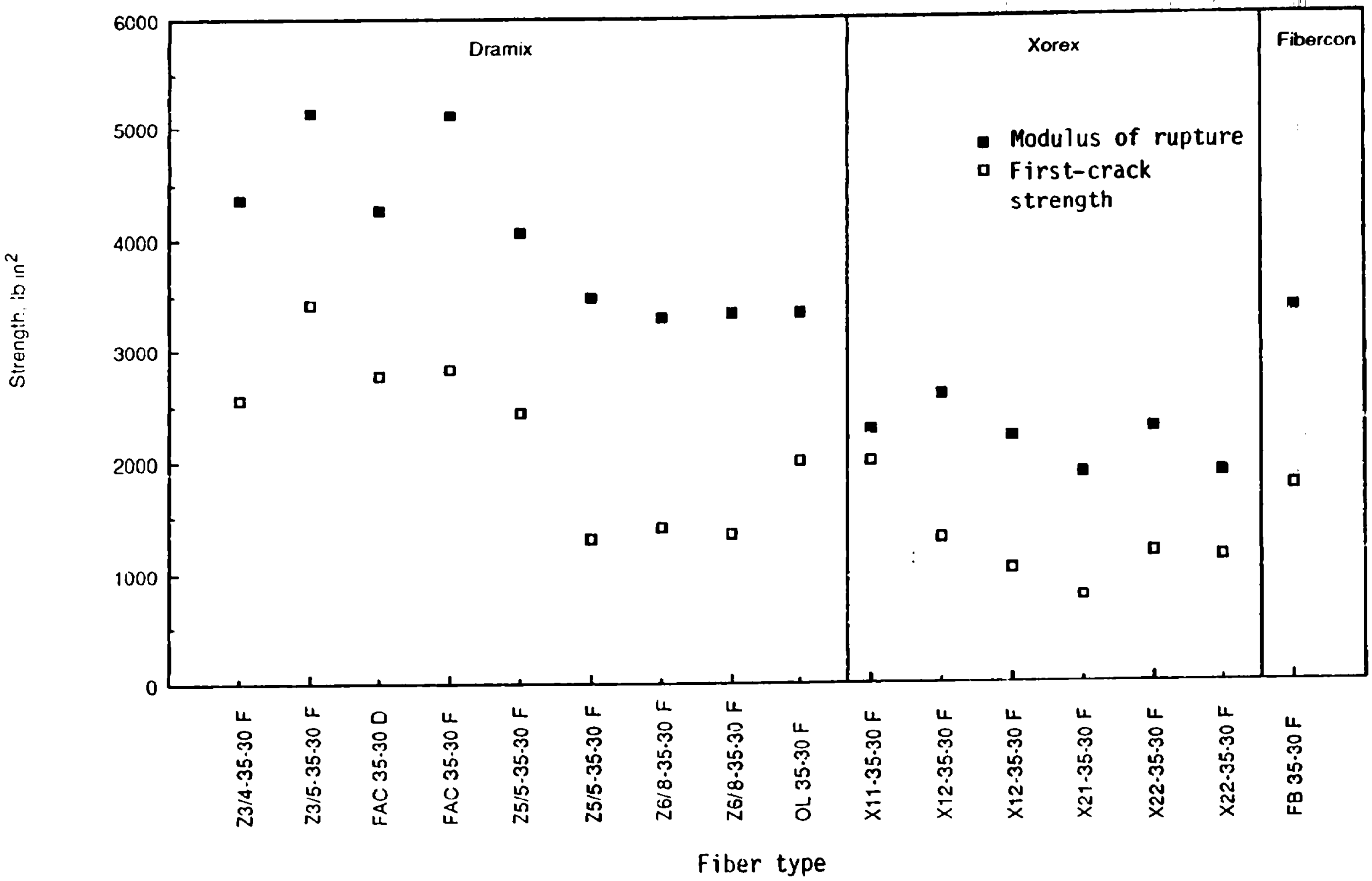


Figure 38. Modulus of rupture and first-crack strength versus fiber type.

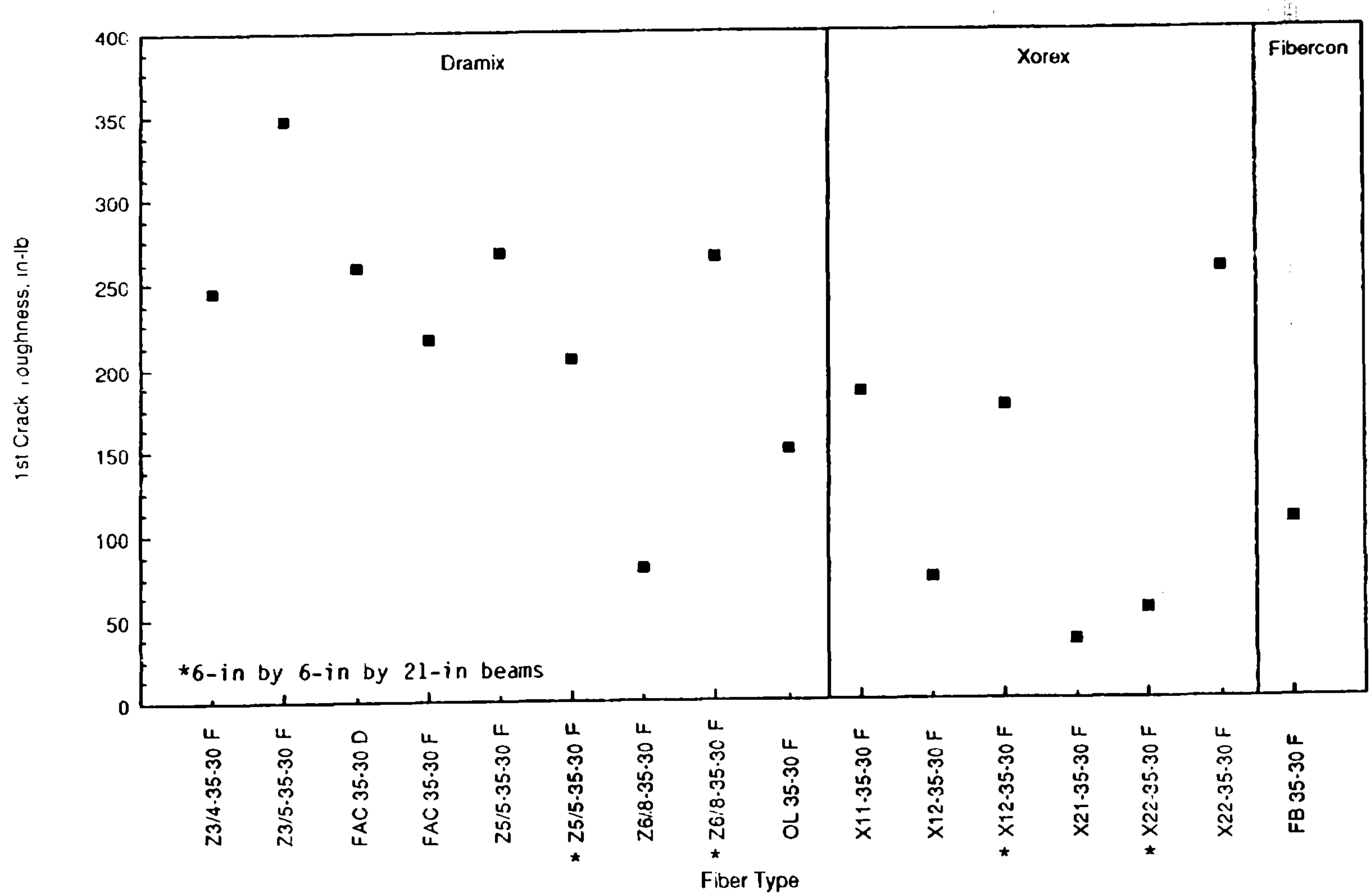


Figure 39. First-crack toughness versus fiber type.

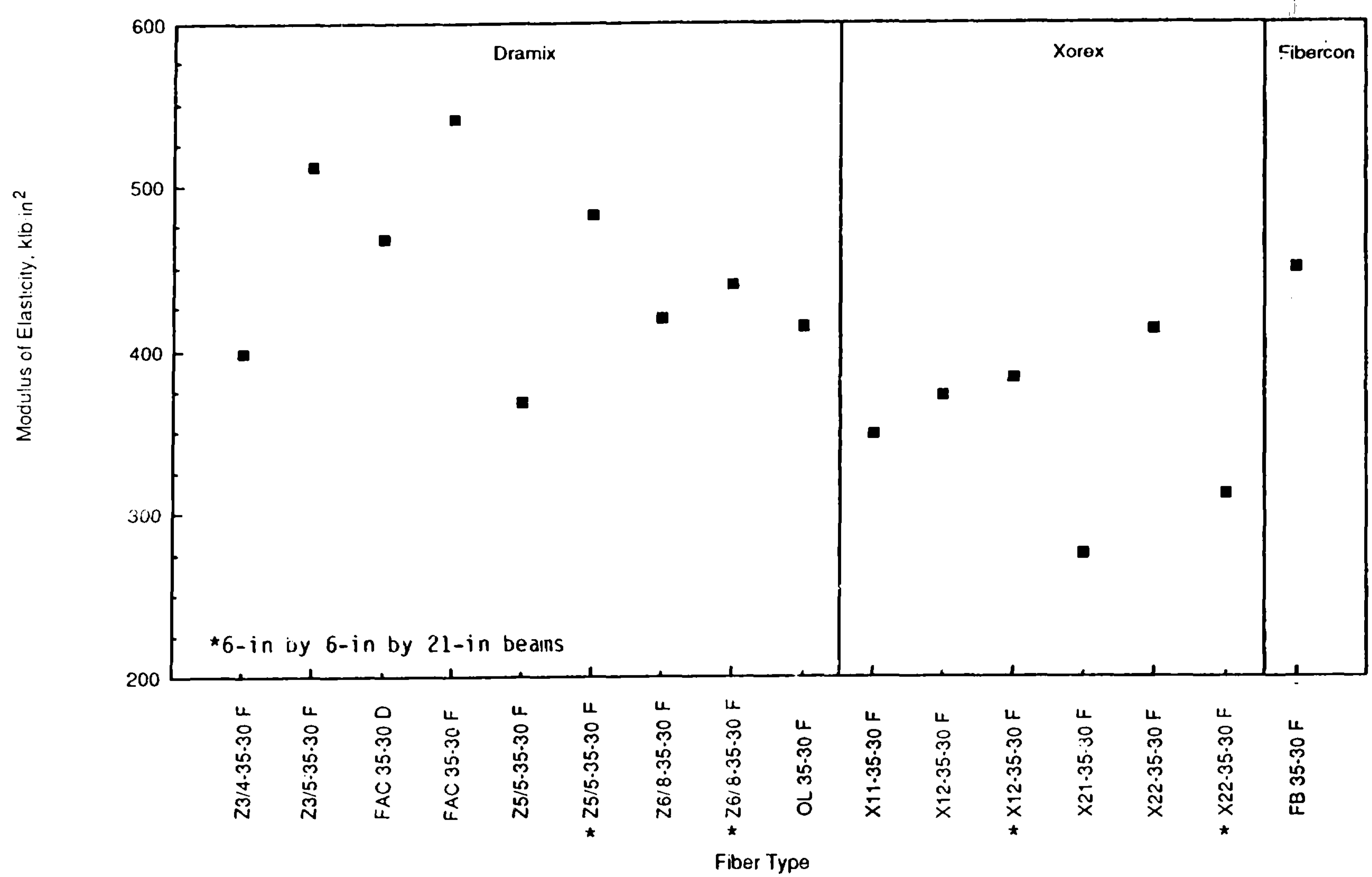


Figure 40. Flexure modulus of elasticity versus fiber type.

Figures 41 and 42 plot the three toughness indexes and two toughness index ratios, respectively. The three toughness indexes parallel one another as expected but show no discernible trends in relationship to the fiber types. This is also the case for the two index ratios.

The effort described in this report for this study group should be considered preliminary only. To isolate individual fiber-type material properties, much more research is needed.

Study Group 4--Sand

General--This study group was designed to investigate the effects on SIFCON compressive and flexural strength with the addition of fine-grained sands. The percentage of sand added was varied while all other mix proportions were kept constant. Table A4 contains all mix designs for this study group.

Three subgroups are included in this study group. Subgroup 4a compares five different types of fine-grained sands for suitability as a slurry ingredient for SIFCON. These five sand-type slurries were compared for fluidity, workability, and compressive strength. Subgroups 4b and 4c vary one specific sand type for a constant W/C + FA ratio of 0.30 and 0.40, respectively. The FA/C + FA percentage was 30 for both these subgroups.

Since sand as an additive was not studied in the previous program, the major consideration of this program was to study fluidity as well as compressive and flexural material properties.

Fluidity--Fluidity measurements were taken for all mixes. All these data are contained in Table 3.

Except for the addition of the sand, the slurry ingredient proportions for subgroup 4a were identical to those of the FAC 35-30 series. Therefore these slurries are included in the table with the sand-type slurries for comparison purposes. The first sand mix of each sand type contained no sand and, therefore, was identical with the FAC 35-30 proportions. In general, these slurries tended to be slightly less fluid and had lower open times

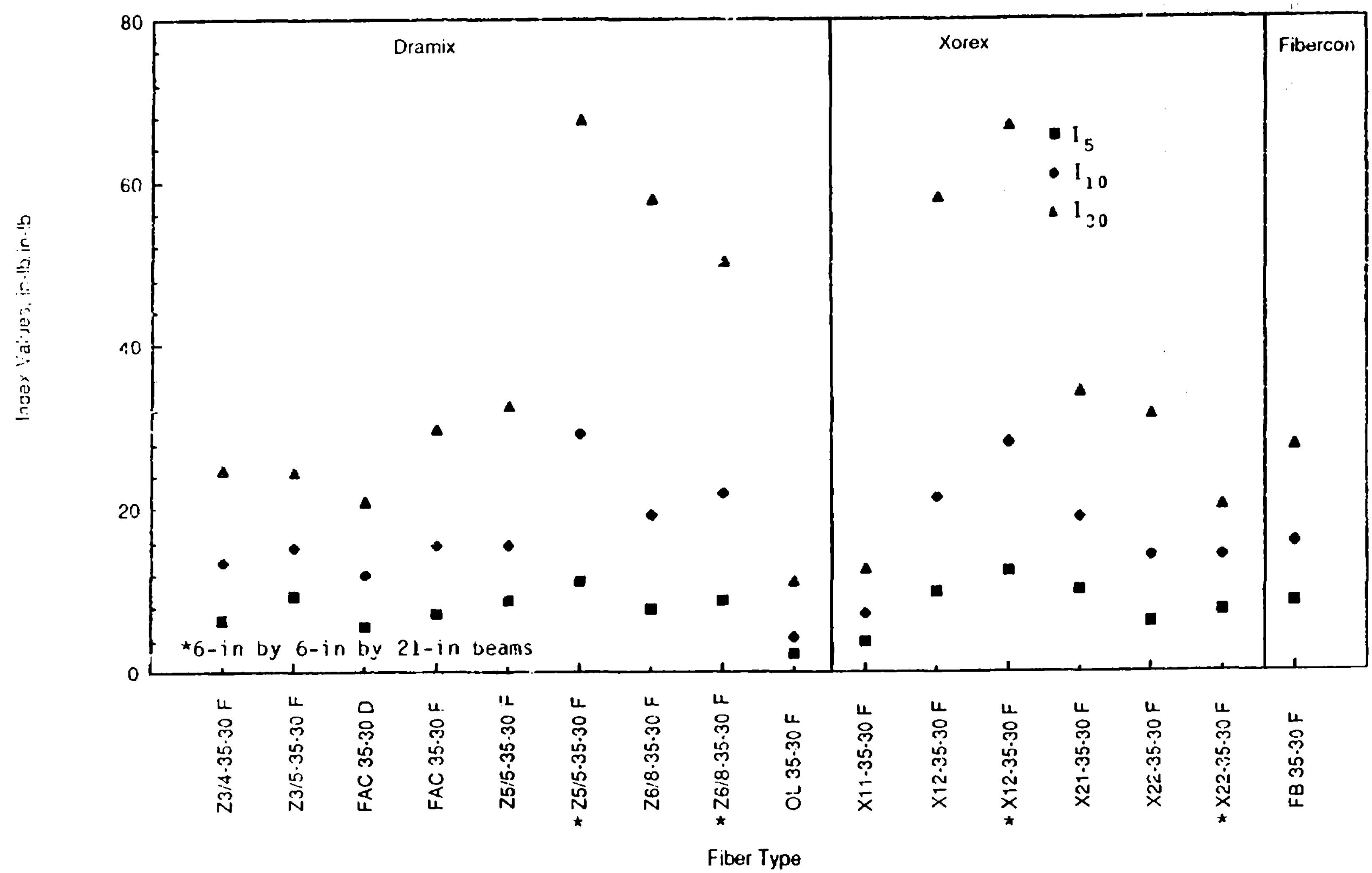


Figure 41. I_5, I_{10}, and I_{30} indexes versus fiber type.

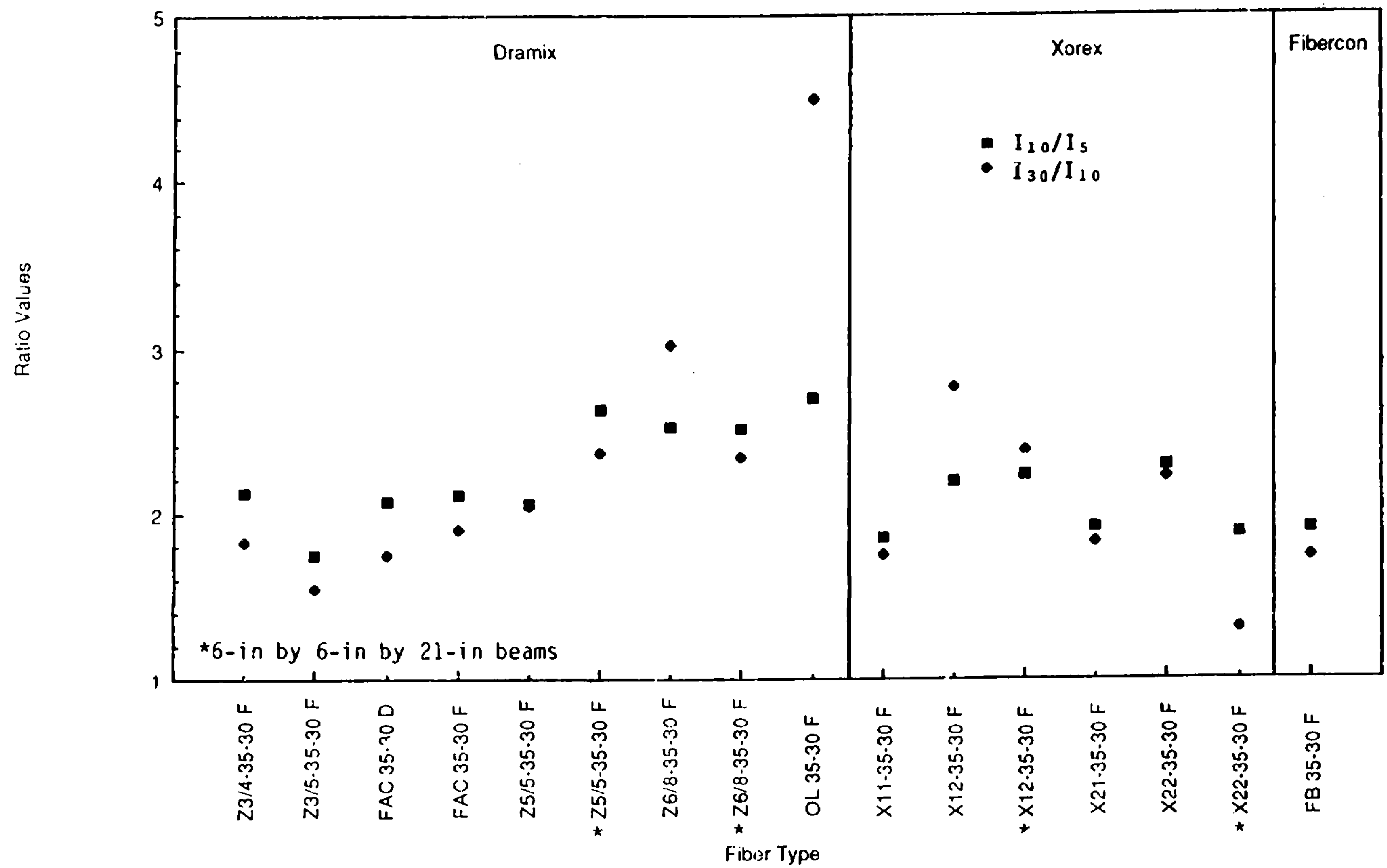


Figure 42. I_{10}/I_5 and I_{30}/I_{10} ratios versus fiber type.

TABLE 3. SAND FLOW MEASUREMENTS

Subgroup 4a (Sand types)

Mix identification code	7	30	45	60	90	120	150	180
	Measurement time, T (T=x, min) — Flow measurement, s							
Comparison Slurry								
FAC 35-30 C	19	24	28	35	55	82	160	
FAC 35-30 D	18							
FAC 35-30 E	20	32		80	120			
FAC 35-30 F	21	27	36	49	140			
FAC 35-30 S	23			93	Thick			
FAC 35-30 T	20		38	64	130			
Z 3/5-35-30 F	26	64	72	84	Thick			
Brick Sand								
S1-0-35-30	20	27	48	60	135			
S1-25-35-30		33	49	85	Thick			
S1-50-35-30		45	62	106				
S1-75-35-30		63	83					
S1-100-35-30		69	94					
S1-125-35-30		91	111					
S1-150-35-30		102						
Plaster Sand								
S2-0-35-30	20	39	67	247				
S2-25-35-30		47	92	Thick				
S2-50-35-30		53	106					
S2-75-35-30		80	156					
S2-100-35-30		97	165					
S2-125-35-30		136	Thick					
S2-150-35-30		Thick						
Coarse Blasting Sand								
S3-0-35-30	19	38	86	250				
S3-25-35-30		40	104					
S3-50-35-30		50	120					
S3-75-35-30		59	Thick					
S3-100-35-30		93						
S3-125-35-30		118						
S3-150-35-30		Thick						
Medium Blasting Sand								
S4-0-35-30	20	36	76	180				
S4-25-35-30		42						
S4-50-35-30		52	121					
S4-75-35-30		69	139					
S4-100-35-30		93	155					
S4-125-35-30		112						
S4-150-35-30		147						
Fine Blasting Sand								
S5-0-35-30	19	39	67	240				
S5-25-35-30		42	72					
S5-50-35-30		66	139					
S5-75-35-30		90	Thick					
S5-100-35-30		133						
S5-125-35-30		330						
S5-150-35-30		Thick						

Subgroup 4b (W / C + FA = 0.30)

Mix identification code	7	30	45	60	90	120	150	180
FAC 30-30 F	87	Thick						
S 25-30-30 F	150							
S 50-30-30 F	86	Thick						
S 75-30-30 F	71	210						

Subgroup 4c (W / C + FA = 0.40)

Mix identification code	7	30	45	60	90	120	150	180
FAC 40-30 F	14	15	16	18	22	31	47	68
S 50-40-30 F	13	15	15	16	19	23	27	32
S 100-40-30 F	19	53	60	84	98	113		
S 150-40-30 F	20		39	41	51	61	71	81
S 200-40-30 F	34	49		75	88	116		

than the FAC 35-30 series. Both fluidity and open time decreased as the sand percentage increased for each sand type. The brick sand mixes were consistently more fluid and also tended to display longer open times in comparison with each corresponding sand mix of the other sand types. All the other sand-type mixes tended to have about the same fluidity and open time. From laboratory observations, the brick sand and plaster sand mixes appeared to be the most workable. This is probably attributable to the more uniformly graded sieve analysis of these two sands. The sand sieve analysis and other properties of each sand type are contained in Table J5. For fiber infiltration, it appears that the brick sand would be the most desirable sand of these five to use in SIFCON.

The fluidity measurements of subgroups 4b and 4c are also contained in Table 3. Brick sand only was used in all these mixes. The low 0.30 W/C + FA ratio of subgroup 4b produced very viscous slurries with very little open time. Fiber infiltration was difficult for all successful mixes and impossible for mixes with a ratio of more than 75 percent sand to cement. SIFCON slurries with a W/C + FA ratio this low are not recommended for most uses. Subgroup 4c with a 0.40 W/C + FA ratio contained mixes that were relatively fluid. Both the fluidity values and the open time tended to decrease with an increase in sand percentage. This would be expected. These mixes appeared to infiltrate the ZL 30/50 fibers with some difficulty. It seems that this range of mixes may be useful in some applications, especially with other less dense fiber-type SIFCONS. Subgroups 4b and 4c also demonstrate that more sand can be added to slurries if the water content also increases.

An observation typical of sand slurries was the tendency of the fibers to filter the sand out of the slurries. This tended to leave a greater concentration of sand at the top of the specimen than at the bottom. The extent of this tendency varied with the sand percentage and the fluidity of slurry. When the percent of sand is greater and/or the fluidity of the slurry is less, there is a greater tendency to filter sand. When enough sand was filtered out, infiltration was blocked by the sand layer. This situation leaves large voids in the SIFCON. Finer grained sands should be studied to see if they may be more suitable for SIFCON.

Compression--The compression test results for subgroup 4a are tabulated in Table D4 and plotted in Figure 43. Only slurry cubes were tested since this subgroup was only designed to select a suitable sand for SIFCON. A simple linear regression curve fit of the data (Fig. 43) shows that the slurry strengths are only slightly affected by the addition of sand. The plots show at best a slight decrease in strength with an increase in the percentage of sand. The data contained in Table D4 for this subgroup show that this tendency may be negligible. By averaging the strength values of each sand type, one can see that these averages are rather close to the average of the comparison slurries. In fact, the brick sand (7784 lb/in^2) and fine blasting sand (7713 lb/in^2) strengths averaged higher than that of the comparison group (7642 lb/in^2). The value shown as an average variation represents the variation of the strength values that are averaged. All these average variation values are significantly lower than those of the comparison slurries (21.85 percent). This probably indicates that the strength values may simply represent normal test variations instead of actual diminishing strength trends with increased sand percentages. Also of interest is the average of all combined sand slurries. This average of 7508 lb/in^2 is only slightly lower than the 7642 lb/in^2 average of the comparison slurries. The variation of 22.42 percent of all the sand slurries combined is only slightly higher than the 21.85 percent of the comparison slurries.

All test results and fluidity measurements indicate that the brick sand was the best sand of the five considered for SIFCON. The plaster sand also appears to be very acceptable. These results also indicate that sands can be used without significant strength losses. This is very advantageous when economy is a factor.

An inconsistency in the sand mix designs existed. After the program was completed, it was discovered that the sand percentages calculated for subgroup 4a were inconsistent with those of subgroups 4b and 4c. In subgroup 4a the sand percentages were calculated on the basis of cement plus fly ash, while those of subgroups 4a and 4c were based on cement only. Therefore, the mix identification codes for subgroup 4a are misleading. They indicate lower sand content t[illegible] was actually present in the mixes. This inconsistency should be kept in mind when interpreting Figure 43 and Tables A4 and D4.

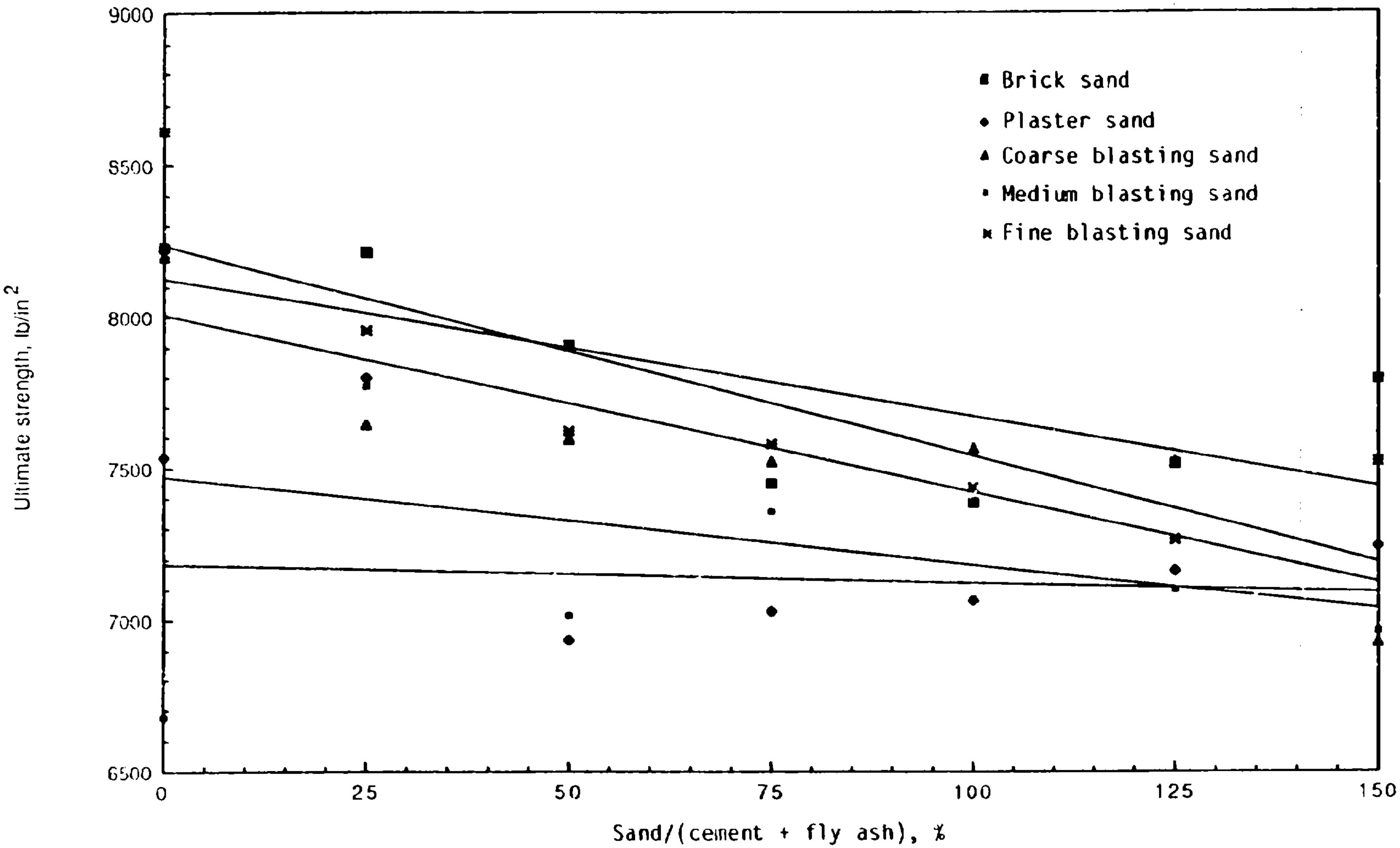


Figure 43. Ultimate cube compressive strength versus sand/(cement + fly ash) (W/C + FA 0.35).

The plotted SIFCON compression results for brick sand of subgroups 4b and 4c are presented in Figures H1, H3, and 44. Figure 44 combines Figures H1 and H3. Figure H1 presents the compression results of subgroup 4b with a W/C + FA ratio of 0.30. Even though the slurry strength does not increase with increased sand percentages, the SIFCON shows a slight increase. One might expect a decrease instead. There may not have been enough tests performed to be conclusive. Figure H3 for subgroup 4c with a W/C + FA ratio of 0.40 shows the same trends. For the two sets of simple linear regression curve fits of the data, the strengths ranged from 11,800 to 13,200 lb/in^2 for subgroup 4b over a sand/cement percent range of 0 to 75, and 9,700 to 13,400 lb/in^2 for subgroup 4c over a sand/cement percent range of 0 to 150. Figure 44 combines the results of Figures H1 and H3 for both SIFCON and slurry at the two respective W/C + FA ratios. The range of strengths of subgroup 4c are lower than that of subgroup 4b because of the lower W/C + FA ratio of subgroup 4c.

Flexure--The same flexure parameters as those studied in Study Group 1 were compared in this study group. The results are tabulated in Table D4.

Figures H2, H4, and 45 present the strength comparisons of both the modulus of rupture and first-crack strength for subgroups 4b and 4c. Figure 45 combines Figures H2 and H4. Both sets of curves demonstrate an increase in strength with an increase in the percent of sand/cement. Again, this may not be expected. For the two sets of simple linear regression curve fits of the data, the modulus of rupture values ranged from 4750 to 5920 lb/in^2 for subgroup 4b, and 4400 to 4800 lb/in^2 for subgroup 4c over a sand/cement percent range of 0 to 75 and 0 to 200, respectively. The sets of first crack strengths show similar trends as the modulus of rupture. The linear curve fit for the two curves ranged from strengths of 3050 to 3440 lb/in^2 for subgroup 4b, and 2300 to 3350 lb/in^2 for subgroup 4c over the same range of sand/cement percentages. Figure 45 combines the results of Figures H2 and H4 for both SIFCON modulus of rupture and first-crack strength at the two respective W/C + FA ratios. Again, the subgroup with the lower W/C + FA ratio provides the higher strengths.

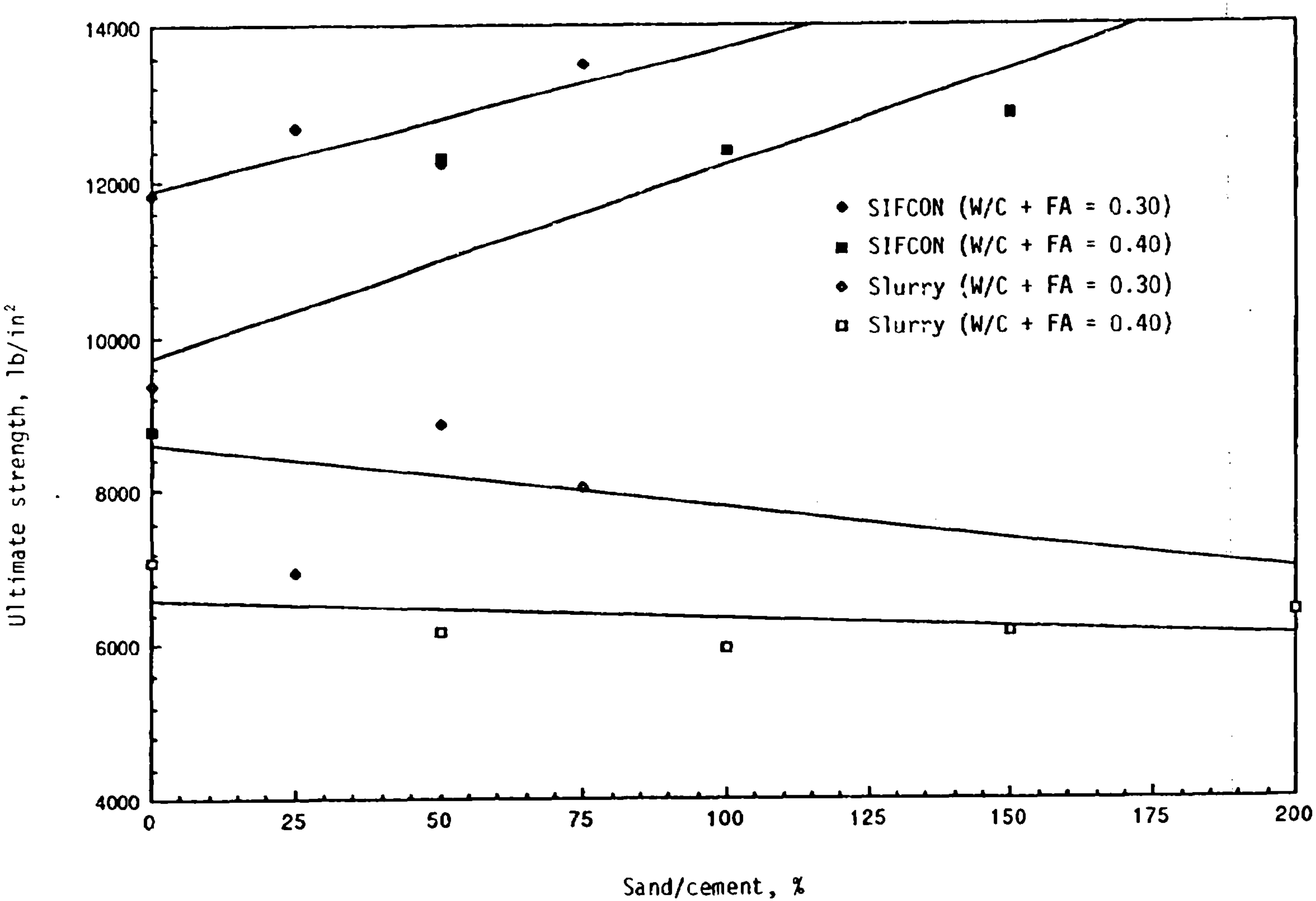


Figure 44. Ultimate compressive strength versus brick sand/cement (combined).

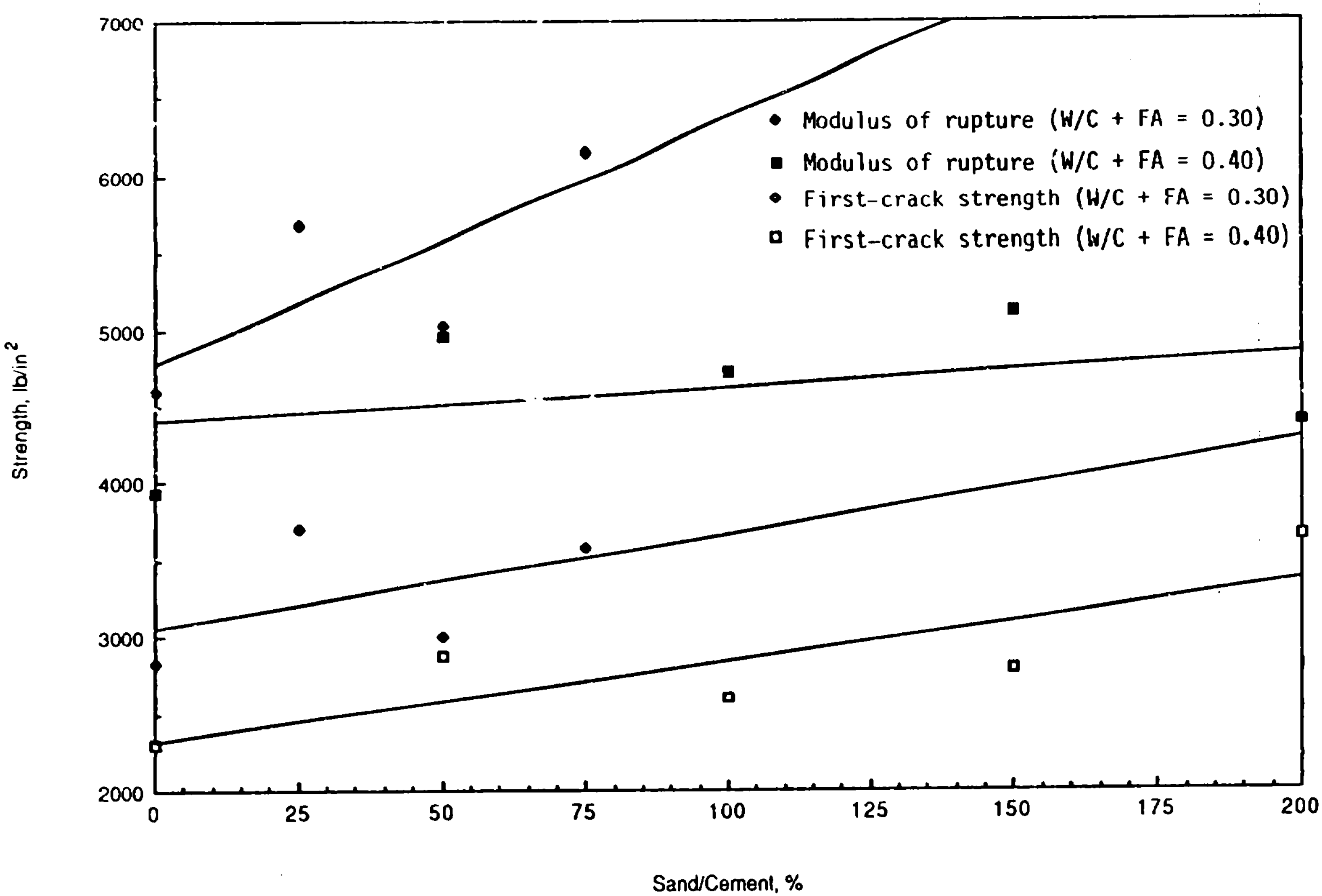


Figure 45. Modulus of rupture and first-crack strength versus brick sand/cement (combined).

Figures 46 and 47 present the flexure modulus of elasticity for the SIFCON in subgroups 4b and 4c, respectively. In the Figure 46 plot, there is an increase in the modulus of elasticity as the sand/cement percent increases, while in Figure 47 there is a decrease. The simple linear regression curve fit for the two curves ranged from 478 to 621 k/in^2 for subgroup 4b over a sand/cement percentage of 0 to 75, and 550 to 375 k/in^2 for subgroup 4c over a sand/cement percentage of 0 to 200. The scatter in the data as well as the fact that only a few test results were available may account for this difference in trends.

The same SIFCON toughness parameters as those of Study Group 1 were compared for this study group also. The comparisons of first-crack toughness are presented in Figures 48 and 49 for subgroups 4b and 4c. The data of the first-crack toughness for subgroup 4b were very scattered. If any trend is evident, it is that of an increase with an increase in the percent of sand/cement. The plot for subgroup 4c also shows an increasing trend with an increase in sand content. From the simple linear regression curve fits, the first-crack toughness ranged from 300 to 330 in-lb for a sand/cement percent of 0 to 75 for subgroup 4b, and 50 to 660 in-lb for a sand/cement percent of 0 to 200 for subgroup 4c. The plots of I_5, I_{10}, and I_{30} toughness indexes against sand/cement percent are presented in Figures 50 and 51 of subgroups 4b and 4c, respectively. The three curves of subgroup 4b each tend to increase linearly very slightly with an increase in sand content. The range of these indexes from the simple linear regression curve fits include 6.1 to 8.3 for I_5, 12.0 to 16.6 for I_{10}, and 22.2 to 28.4 for I_{30} over a sand/cement percent range of 0 to 75. The three curves of subgroup 4c show the opposite trend. The range of these indexes for the simple linear regression curve fits include 8.0 to 3.8 for I_5, 17.0 to 8.2 for I_{10}, and 32.0 to 17.0 for I_{30} over a sand/cement percent range of 0 to 200. The related I_{10}/I_5 and I_{30}/I_{10} toughness ratios are plotted in Figures 52 and 53 for subgroups 4b and 4c, respectively. The ratios for subgroup 4b tend to decrease with an increase in sand content, while those of subgroup 4c tend to increase.

Except for a few exemptions, for most parameters there was an increase in strength for a corresponding increase in the sand content in the SIFCON tested. Even though this may not be expected, it does indicate that the

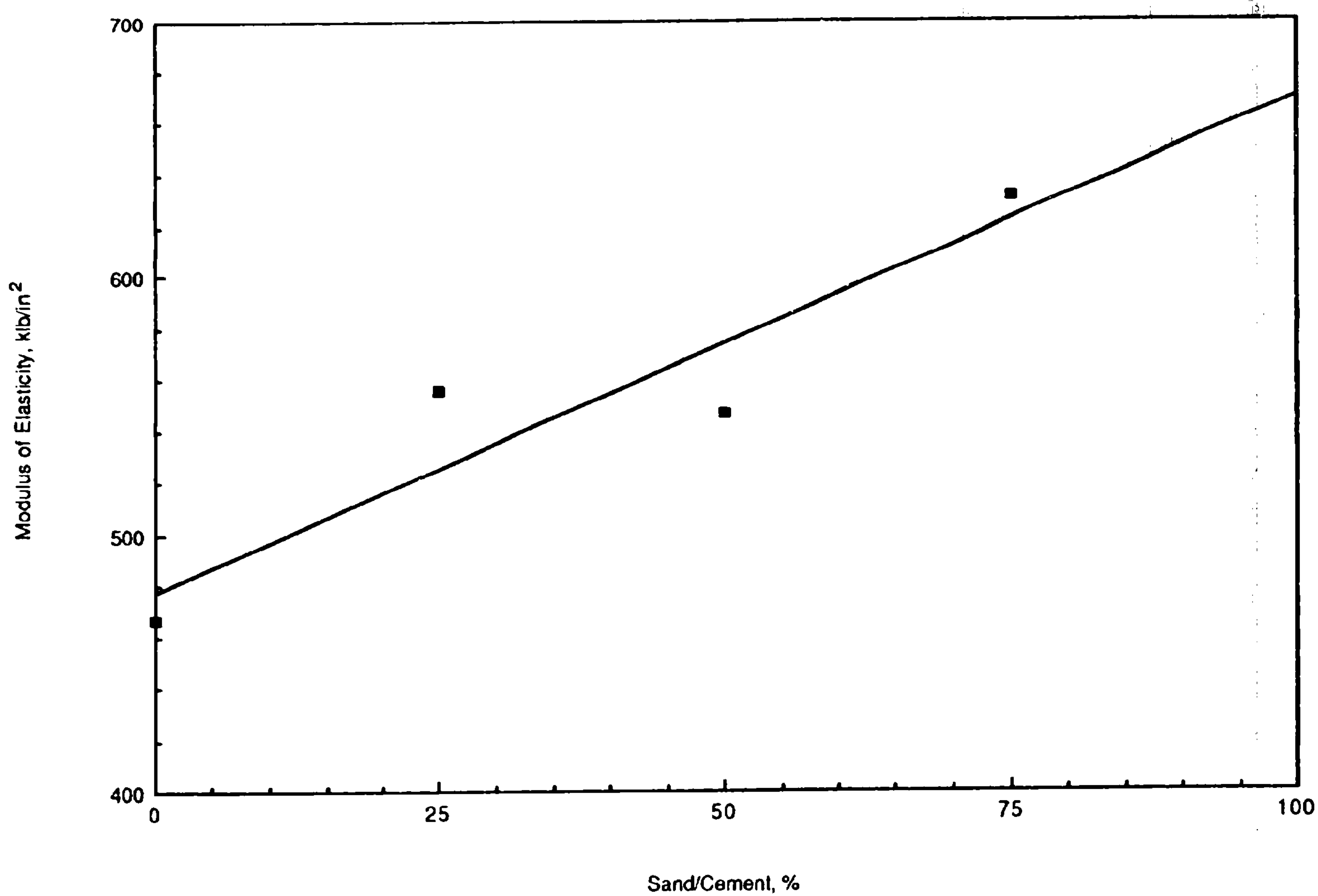


Figure 46. Flexure modulus of elasticity versus brick sand (W/C + FA = 0.30).

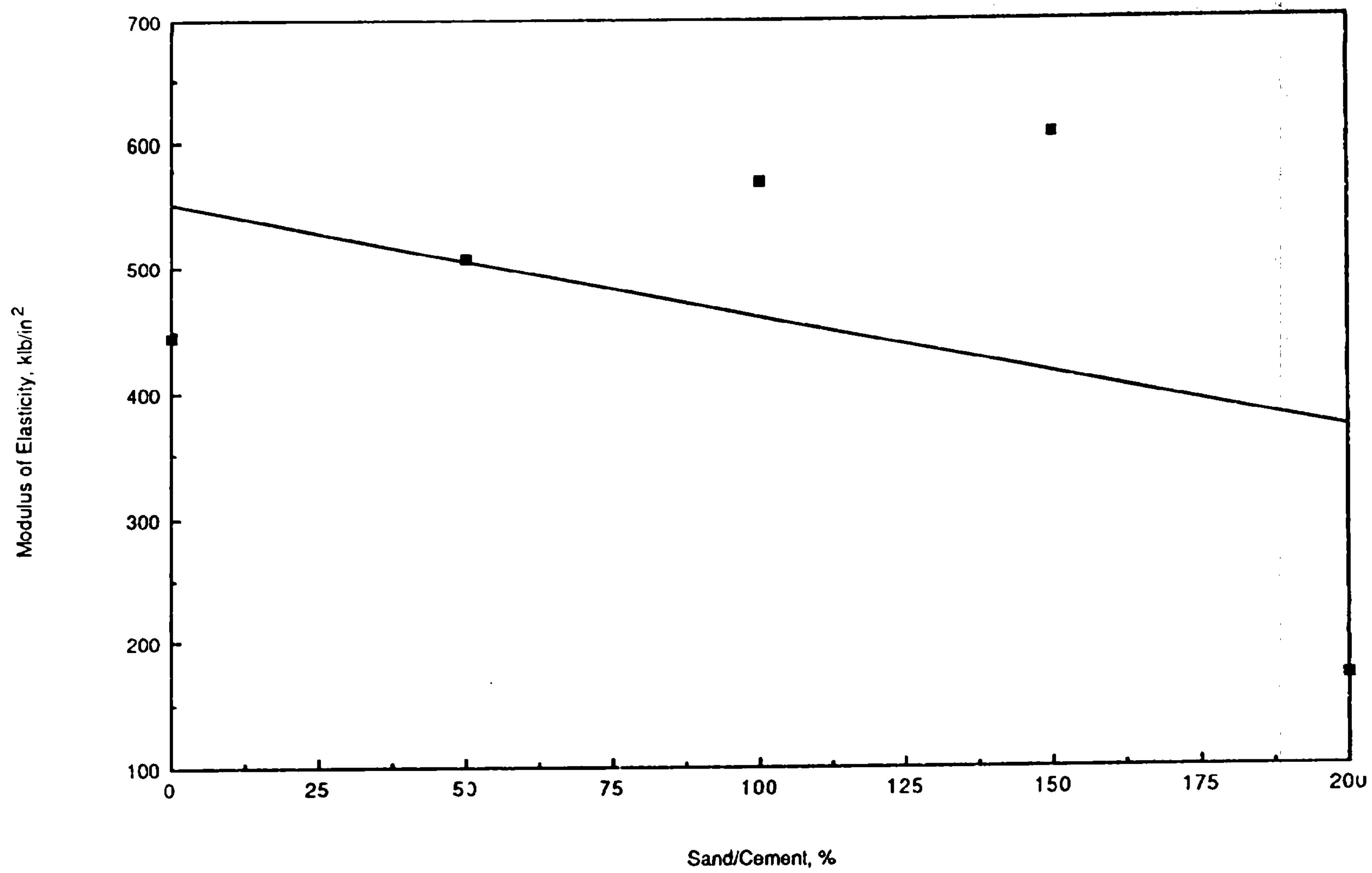


Figure 47. Flexure modulus of elasticity versus brick sand (W/C + FA = 0.40).

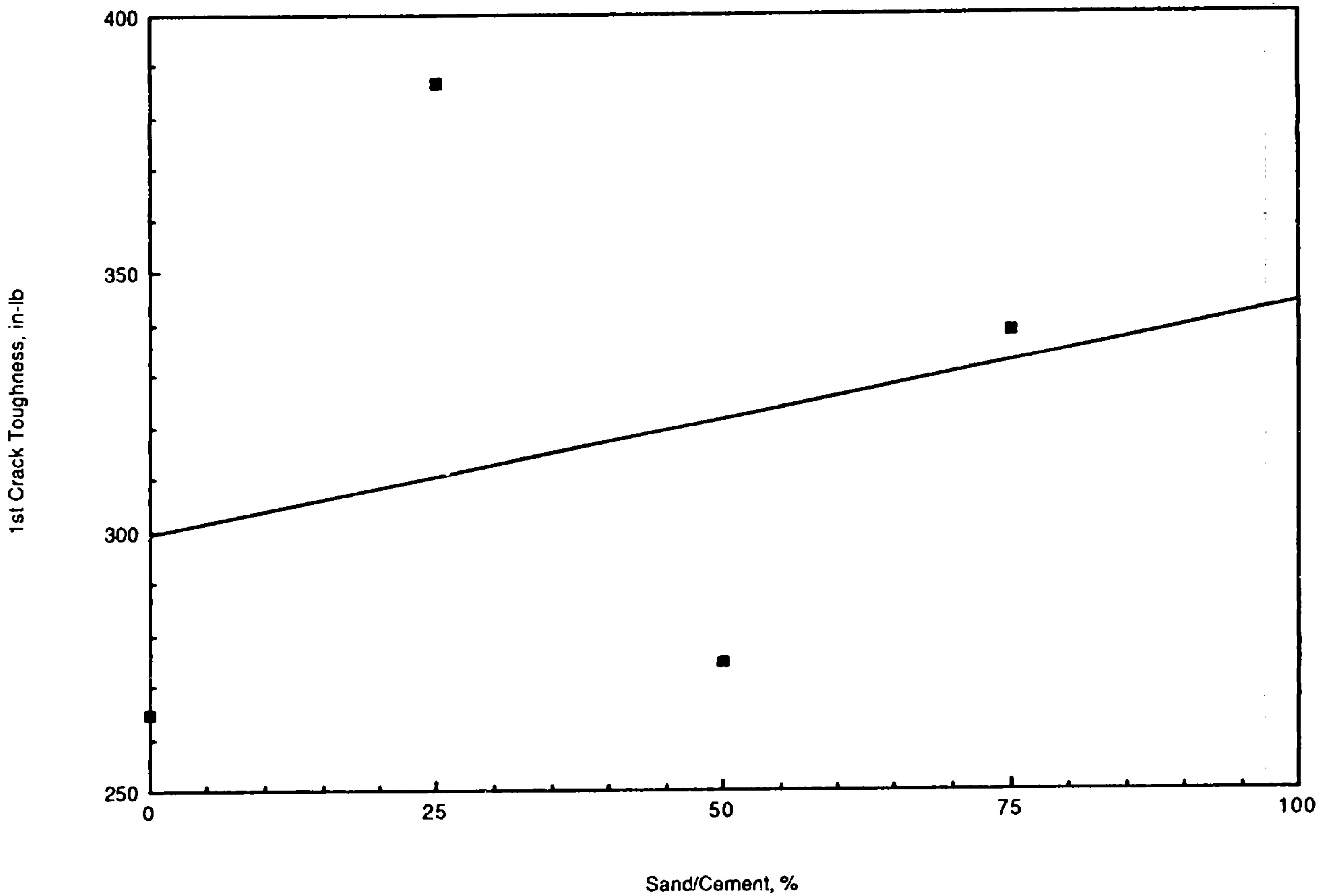


Figure 48. First-crack toughness versus brick sand (W/C + FA = 0.30).

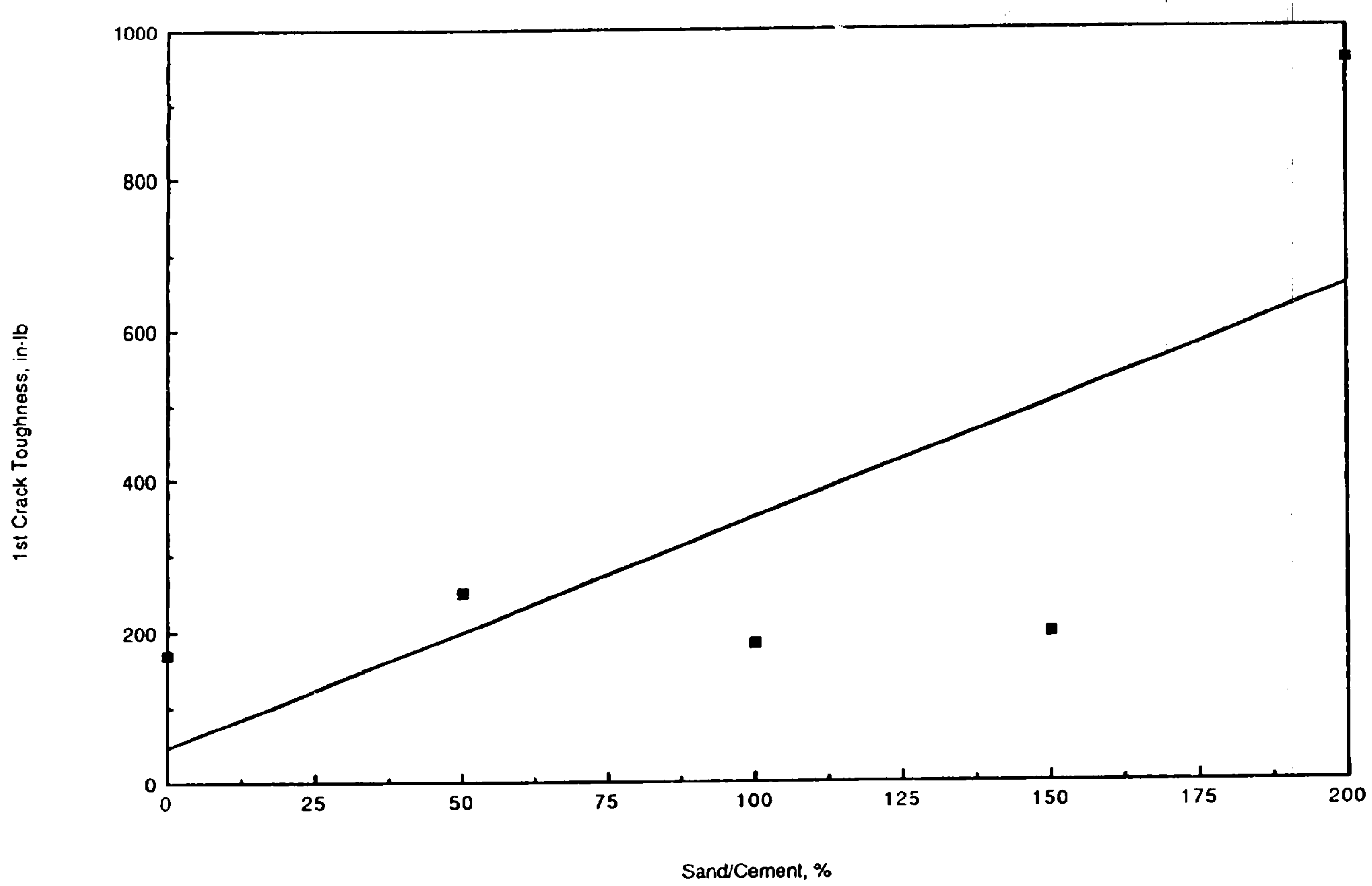


Figure 49. First-crack toughness versus brick sand (W/C + FA = 0.40).

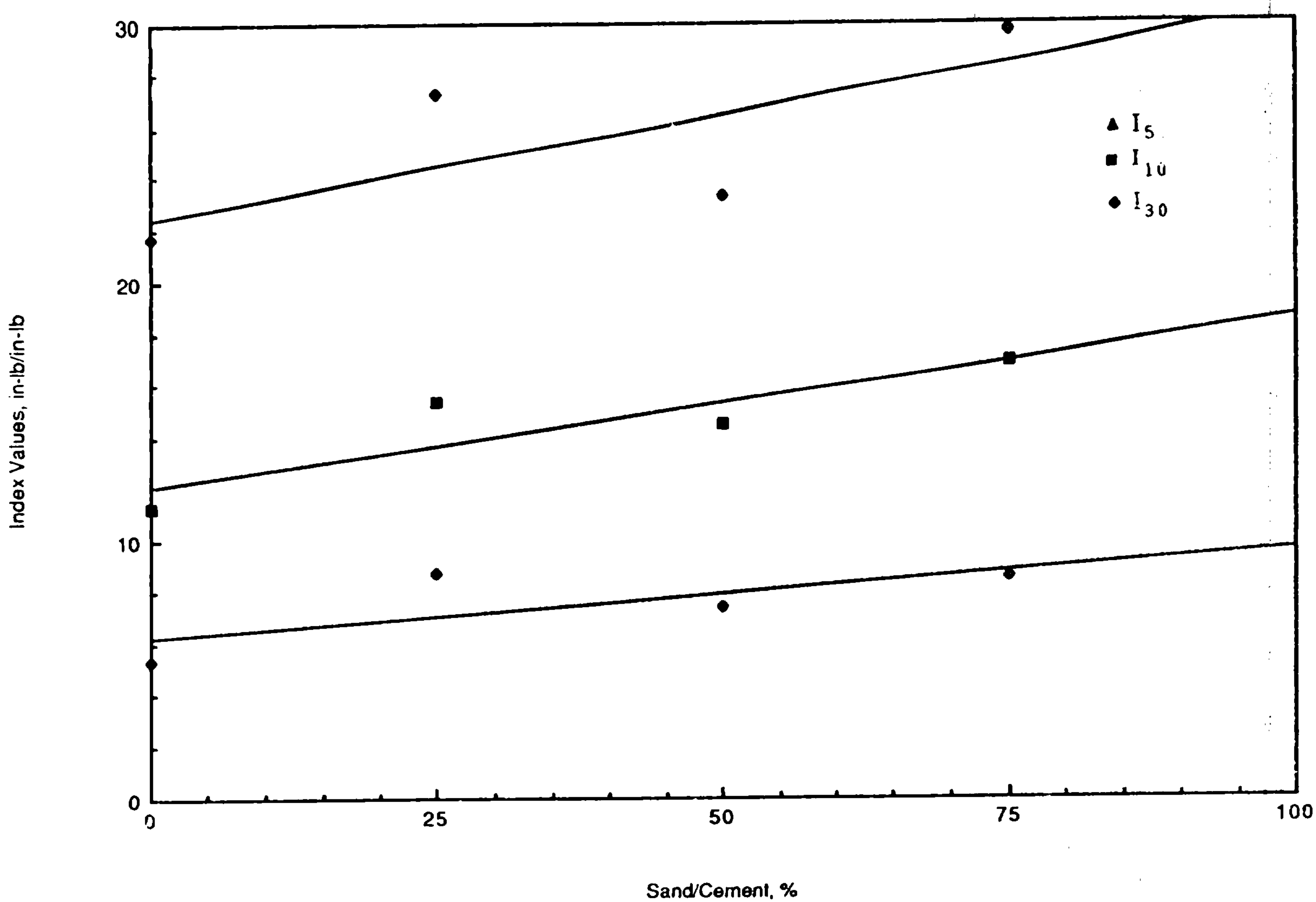


Figure 50. I_5, I_{10}, and I_{30} indexes versus brick sand (W/C + FA = 0.30).

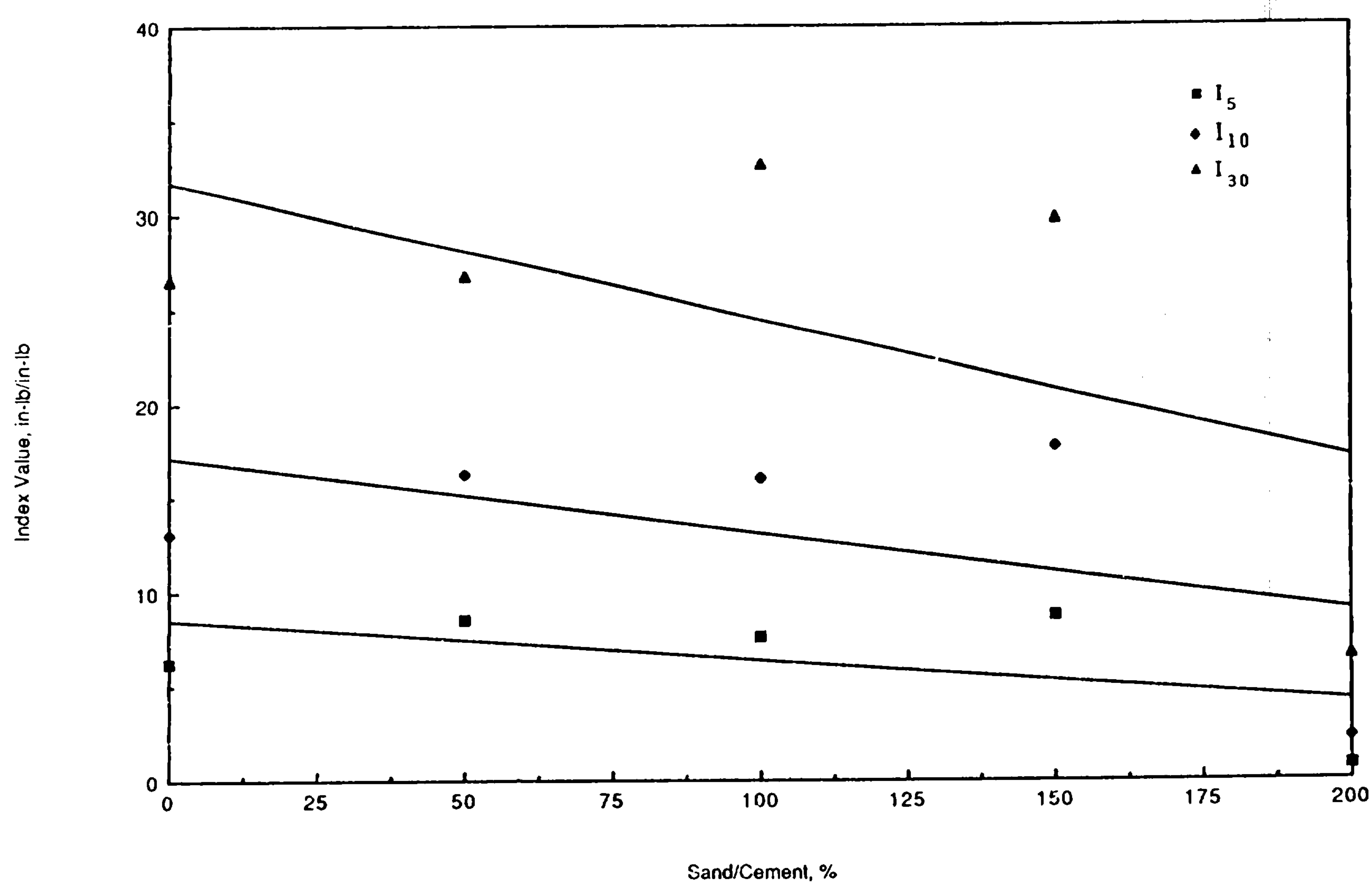


Figure 51. I_5, I_{10}, and I_{30} indexes versus brick sand (W/C + FA = 0.40).

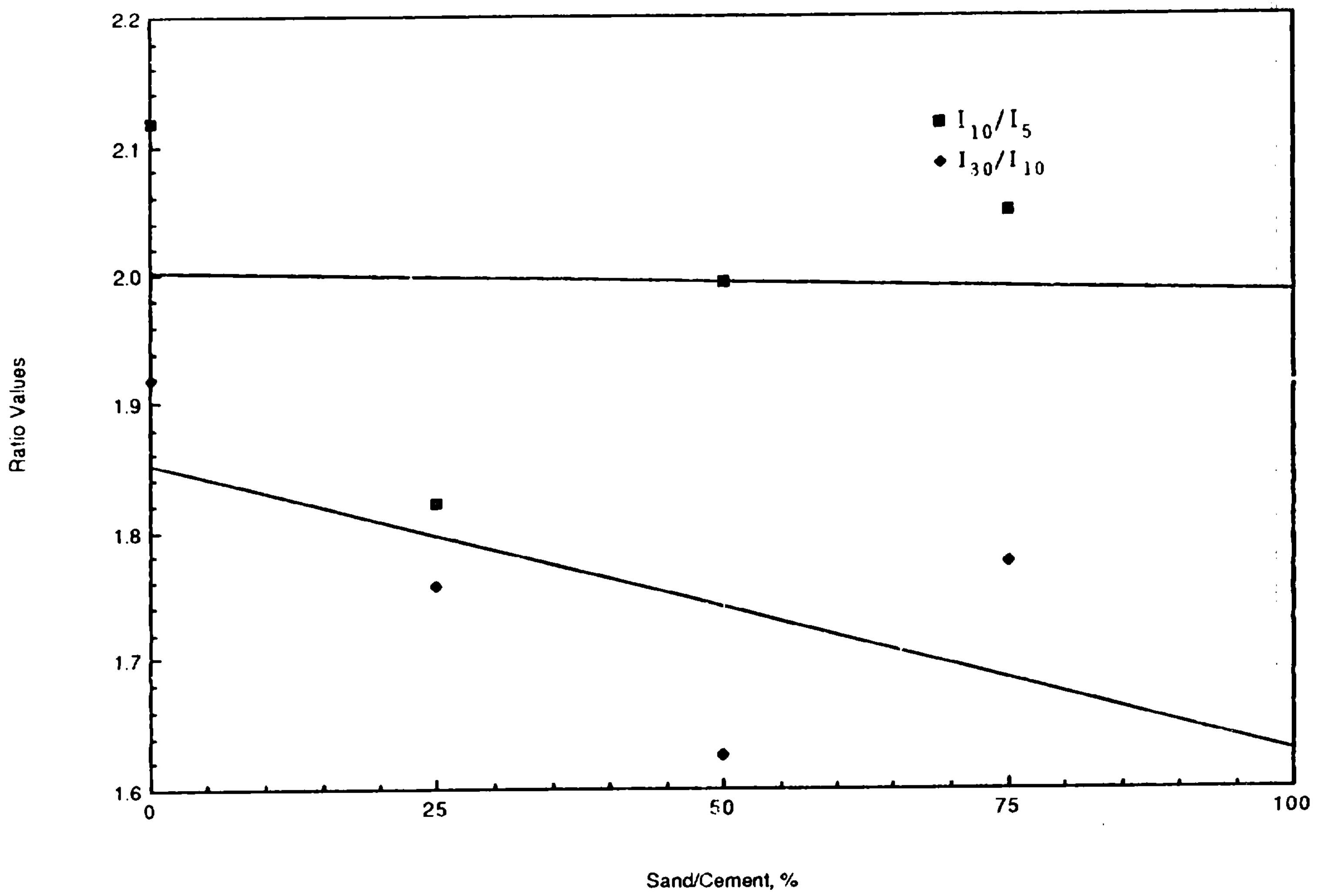


Figure 52. I_{10}/I_5 and I_{30}/I_{10} ratios versus brick sand (W/C + FA = 0.30).

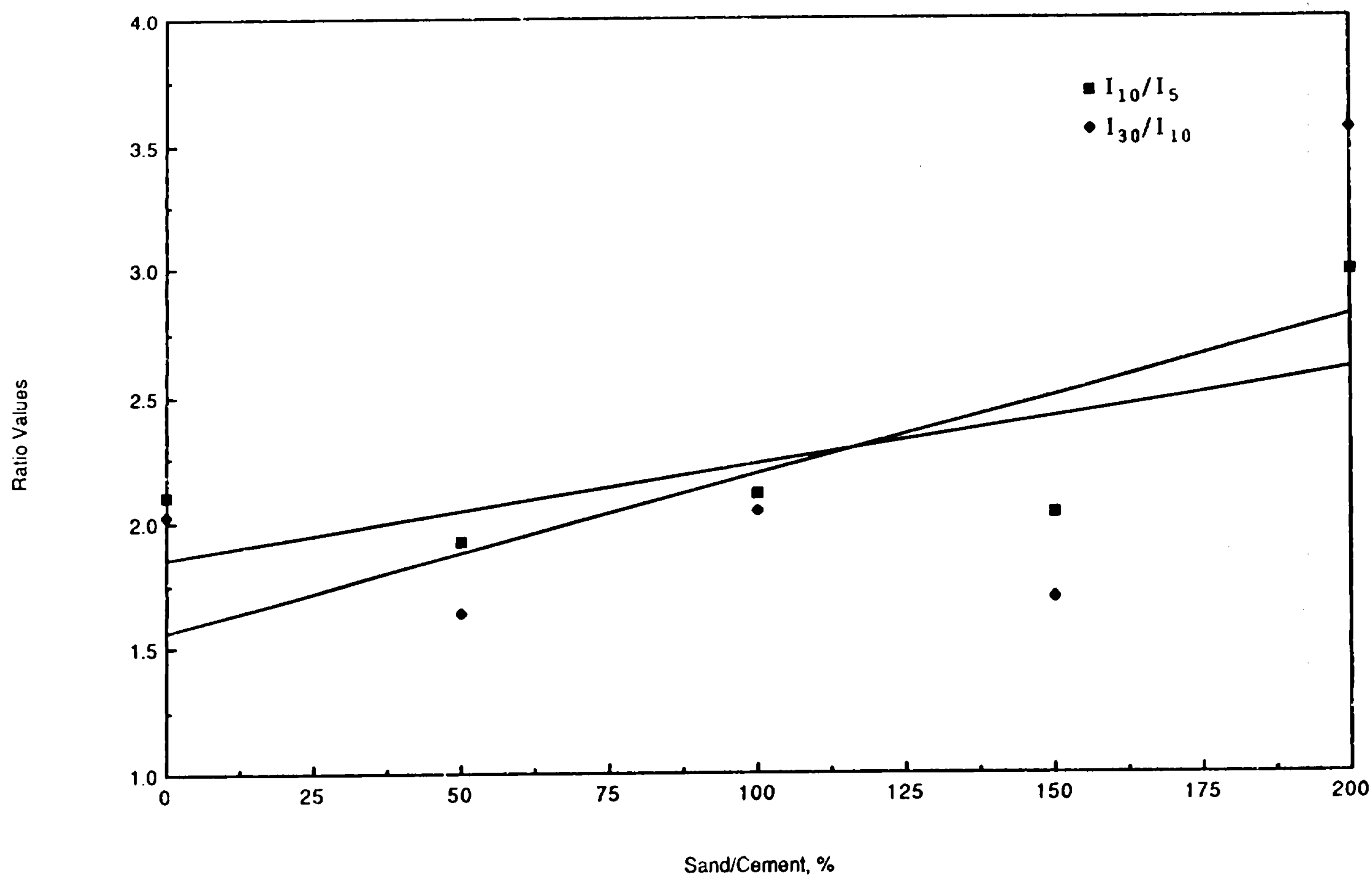


Figure 53. I_{10}/I_5 and I_{30}/I_{10} ratios versus brick sand (W/C + FA = 0.40).

addition of fine-grain sand to SIFCON can be very advantageous. The addition of sand probably helps control shrinkage cracking in the matrix. This may account for the increased strength. This, however, was a preliminary effort requiring further study. Further study is also needed to improve the ability of sand slurries to infiltrate fibers. Most of the slurries produced in this program did infiltrate the fibers, but with some effort and only to the 6-in depth of the specimens. Very few of the slurries studied in this study group would be effective in infiltrating deeper members containing the Dramix ZL 30/50 fibers. In spite of these limitations, sand slurry SIFCONS show much potential.

STUDY GROUPS--TEST METHODS

Study Group 5--Composite beams

General--The major consideration of this study group was to investigate the effects of selectively placing fibers in flexure specimens, because, for a beam loaded in flexure, the greatest bending stresses are at the tension surface. Since these stresses decrease proportionately away from that surface, and since the opposite surface of the beam is in compression, it may be advantageous to place fibers only in a portion of the tension area. The information gained may be useful in the modeling of large-scale actual beams. The specimens prepared for this study group contained various depths of fibers at the tension surface. The depths of fibers included 0, 0.5, 1, 1.5, 2, 3, and 4 in. The rest of the beam was composed simply of the same slurry used to infiltrate those fibers. The production of these composite beams is described earlier in this report.

All the mix designs for this study group are contained in Table A5. The specimens were fabricated on two different occasions using the same mix proportions. The mixes identified as C3-35-30 F, C2-35-30 F, and C0-35-30 F were produced at the same time using the same slurry as FAC 35-30 F. The mixes identified as C1.5-35-30 F, C1-35-30 F, C0.5-35-30 F, and C0-35-30 C were produced at the same time using the same slurry as FAC 35-30 C.

During testing of the specimens, some problems were encountered. Since a point load was applied at all specimen contact points (see Fig. 9),

failure first occurred on the top surface. This failure was not due to the compression stresses associated with bending but to the point loading concentrated stresses on the slurry. Failure cracks began at one or both of the upper contact points, moved vertically or diagonally, and then propagated in a horizontal direction. Failure in the SIFCON area did not begin until the cracking and crushing of the slurry was nearly stabilized (Fig. 13). Because of this irregular redistribution of stresses, the test results are probably somewhat distorted. To obtain more representative data of composite beams, some refinements in this test method are required.

Compression--Compression tests were performed for the two mixes in this group. The results are contained in Table D5. Both the SIFCON ultimate strengths were considerably higher than that of the average of the mixes with the same mix proportions (subgroup 2b). The slurry strengths were closer to the average of the comparable mixes. The strengths for the two mixes included 12,773 and 13,430 lb/in^2 for SIFCON, and 7360 and 8109 lb/in^2 for the slurry for FAC 35-30 C and FAC 35-30 F, respectively. The average strengths of the comparable mixes of subgroup 2b included 11,473 lb/in^2 for the SIFCON and 7642 lb/in^2 for the slurry.

Flexure--Since these data are preliminary, only the modulus of rupture and the first crack strength parameters were plotted for this study group. These data are contained in Table D5 and Figure 54. The curves for these two parameters show an increase in strength with an increased depth of SIFCON. The strengths ranged from 573 to 5116 lb/in^2 for the modulus of rupture and approximately 430 to 2838 lb/in^2 for the first-crack strength over the range of SIFCON depths of 0 to 4 in, respectively. The best curve fit appeared to be a second-order polynomial that begins at a steep slope and then tends to flatten out as it approaches full depth. These trends were expected. Because of the problems encountered during testing, the actual test result values may be lower than those of a more representative test but the trends may be the same. The shape of the two curves seems to indicate that deeper SIFCON layers increase strengths, but that the increase is less and less pronounced as the depth approaches the maximum beam depth.

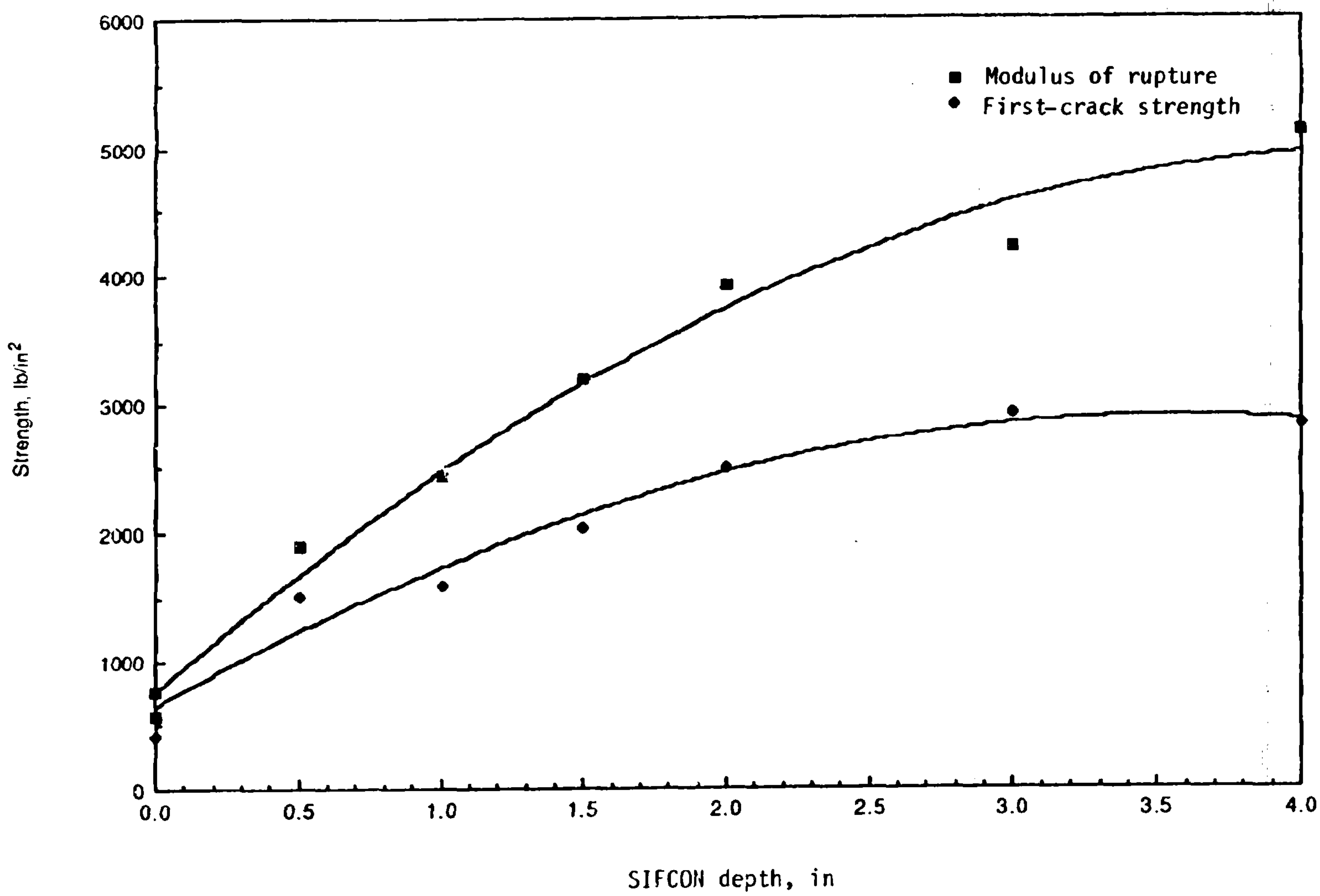


Figure 54. Modulus of rupture and first-crack strength versus composite beam depth.

Study Group 6--Variable depth beams

General--During observations of the flexure tests, it was unclear whether SIFCON specimens were, in fact, failing in flexure. Some specimens appeared to be failing in shear or in a combination of shear and flexure. Since the standard being used to test flexure specimens (ASTM C-1018) was not designed necessarily for SIFCON, it was determined that some study of this test method was needed. This study group was designed to study the effects on strength of varying the span-to-depth of beam ratio. It was believed that the larger the span/depth ratio, the greater the tendency to produce true bending stresses.

This varying span/depth ratio was accomplished by keeping a constant span length of 12 in, but cutting beams of varying depth. One set of long beams was also cut and tested over a span length of 18 in. All beams were molded 4 in wide. The beams were 1, 2, 3, 4, 4 (long beam), and 5 in deep, resulting in span/depth ratios of 12, 6, 4.5 (long beam), 4, 3 (typical), and 2.4, respectively.

Only one mix was produced for this study group--FAC 35-30 D. Several beams were molded from this mix to produce specimens to be tested in both compression and flexure.

Compression--The results of the compression tests for this study group are contained in Table D6. The SIFCON ultimate strength of 9452 lb/in^2 for the one mix of this study group was the lowest strength of all with identical proportions in subgroup 2b. Therefore the average was well below the average of 11,473 lb/in^2 of subgroup 2b. The possible reason for such a low value was discussed earlier with the test results of subgroup 2b. Only relative values are important for Study Group 6. The slurry ultimate strength of 6950 lb/in^2 was also lower than the average of those slurries in subgroup 2b of 7642 lb/in^2.

Flexure--The same flexure parameters as those studied in Study Group 1 were compared in this study group. The results are tabulated in Table D6.

Figure 55 presents the strength comparisons of both the modulus of rupture and first-crack strength for this study group. The data are rather scattered, not showing any very definite trends. There were too few tests to explain the cause of the scatter. The best curve fits seemed to be either exponential or simple linear regression curves. Figure 55 was plotted using an exponential regression curve fit to be consistent with the curves of Figures 56 and 57. If there is a trend at all, it seems to be a tendency toward a decreasing strength with an increase in span/depth ratio. The data scatter is such that the decrease may be negligible and that the results reflect normal SIFCON test result scatter. If the latter is true, then the average strengths of all the tests include 4003 lb/in^2 with a 28.48 percent variation for modulus of rupture and 2595 lb/in^2 with a 47.41 percent variation for first-crack strength.

The flexure modulus of elasticity and first-crack toughness comparisons with span/depth ratio are presented in Figures 56 and 57. These plots are similar to each other and show a definite decrease in values as the span/depth ratio increases. An exponential regression curve fit of the data was selected for both. The actual values ranged from 653 to 17 k/in^2 at span/depth ratios of 12 and 2.4 for the modulus of elasticity, and 529 to 9 in-lb at the same ratios for first-crack toughness.

The various toughness index values and ratios are contained in Figures I1 and I2. The three toughness indexes data show considerable scatter. If there is any trend, it may be an increase in values as the span/depth ratio increases. The toughness index ratios also are inconclusive. If any trend is present in the data, it is that of a slight decrease in the I_{10}/I_5 ratio and a slight increase in the I_{30}/I_{10} ratio with an increase in span/depth ratios.

In conclusion, these limited data seem to indicate that, in general, the standard used for testing flexure specimens is adequate. This problem, however, should be studied further.

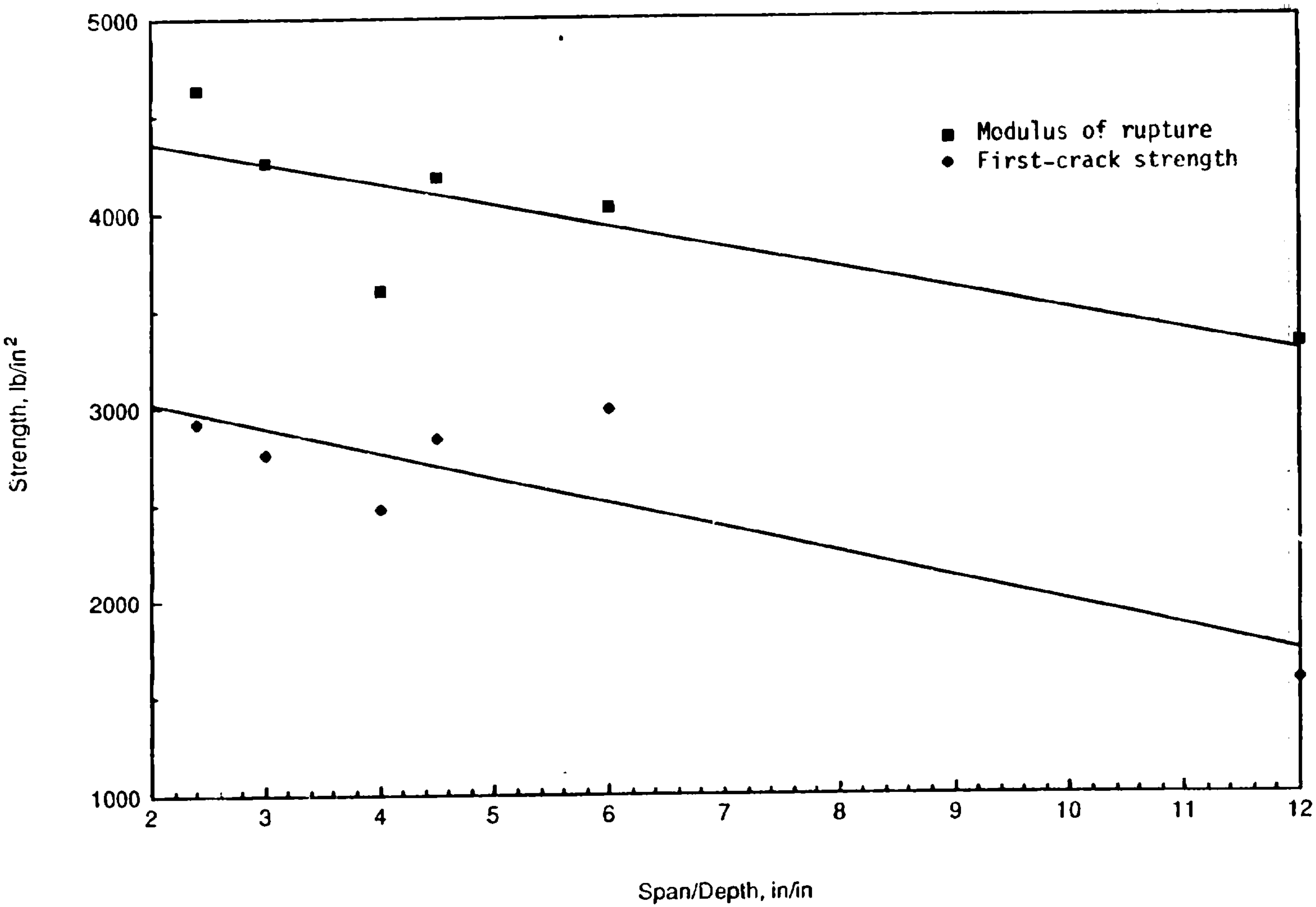


Figure 55. Modulus of rupture and first-crack strength versus span/depth ratio.

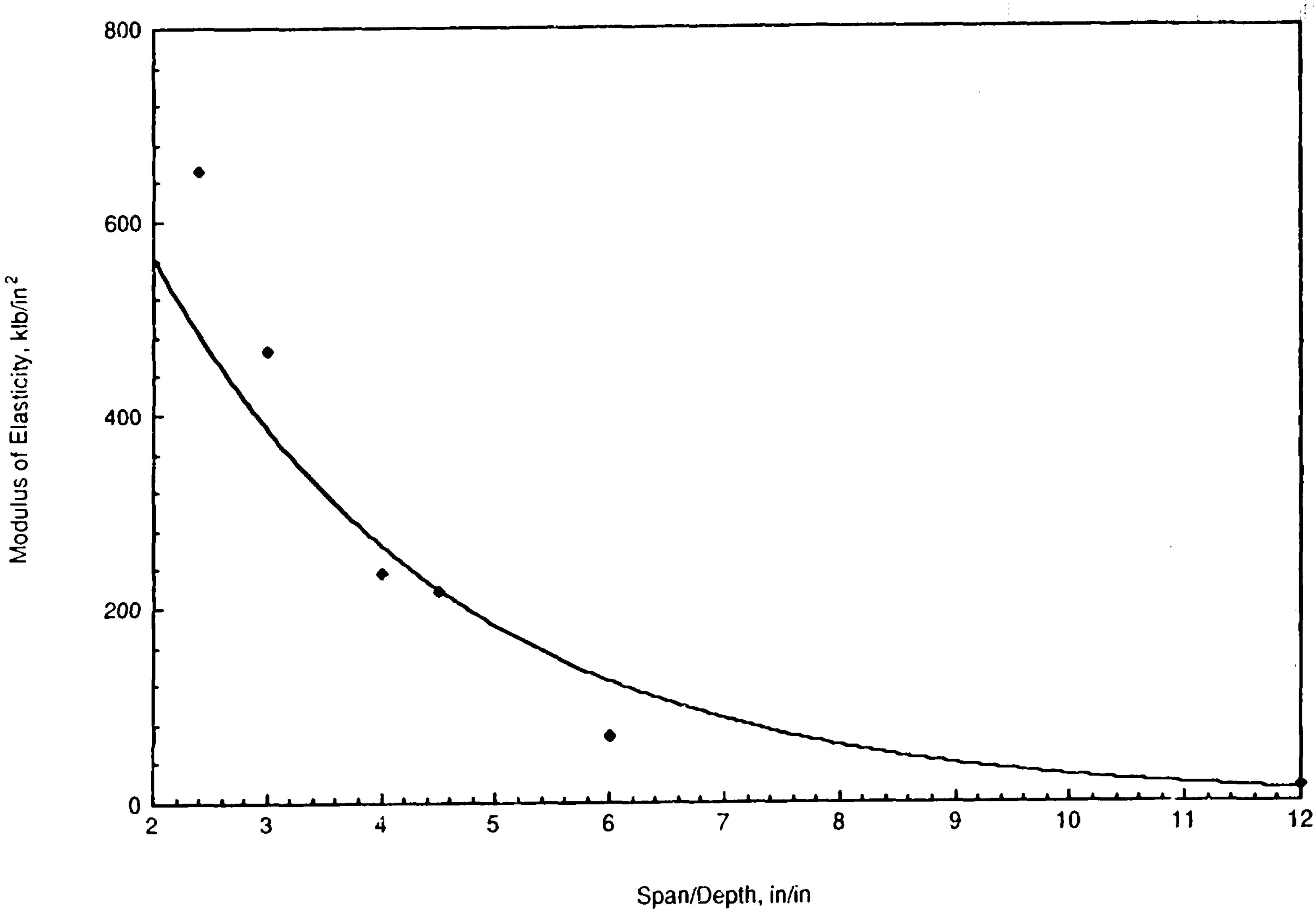


Figure 56. Flexure modulus of elasticity versus span/depth ratio.

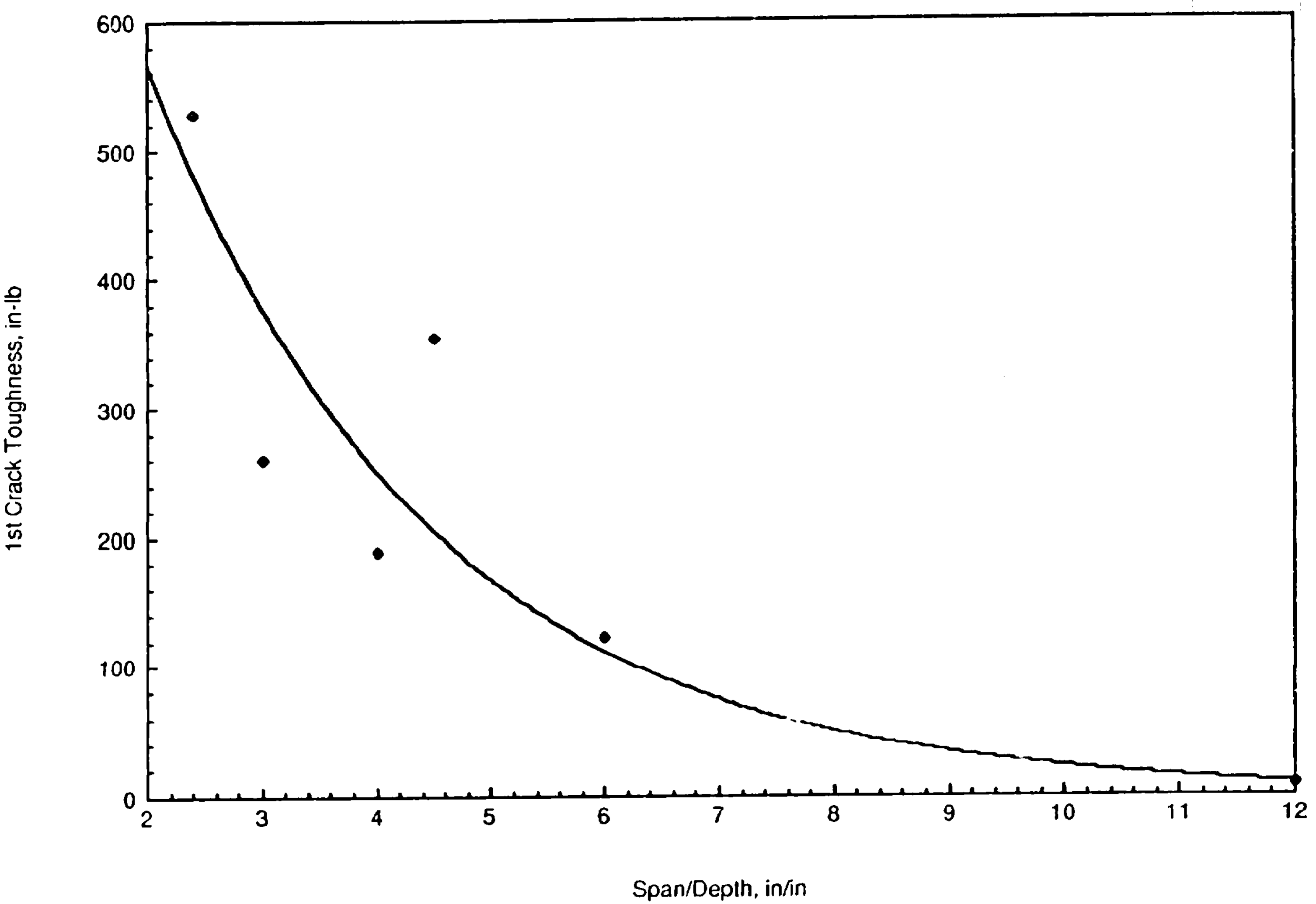


Figure 57. First-crack toughness versus span/depth ratio.

Study Group 7--Edge effects

General--After compression test results were compared with those of the previous program, it was noticed that the results were consistently lower in this program. Reasons for this discrepancy were investigated. All molding, specimen preparing, and testing procedures were reviewed. The testing machine calibration was checked. The laboratory technicians were interviewed for their observations and procedures. Quality control data were studied. After scrutinizing all these items, it was concluded that the only significant difference between the two programs was a procedure used in obtaining compression test specimens. In the previous program, core specimens were removed from a 12- by 15- by 6-in slab, while in this program they were removed from a 4- by 15-by 6-in beam. This appeared to be the major contributing factor. Therefore this study group was initiated to verify this assumption.

This study group consisted of only one slurry mix from which two 8- by 15- by 6-in slabs and two 4- by 15- by 6-in slabs were fabricated. The slurry had the same proportions as the mixes of subgroup 2b. The mix proportions for the slurry are contained in Table A7. Even though the slurry was the same in this group, two different fiber types were used--Dramix ZL 30/50 and ZL 50/50.

The two different sizes of slabs were intended to simulate those of the two programs. The specimens identified as FAC 35-30 E (typical), containing ZL 30/50 fibers, and Z 5/5-35-30 E (typical), containing ZL 50/50 fibers, were molded to simulate the specimens of the present program. The specimens identified as FAC 35-30 E (control) and Z 5/5-35-30 E (control) were molded to simulate the previous program.

Results--The stress/strain curves for the four sets of specimens tested are presented in Figures C82 through C85. Figure 58 superimposes the two average stress/strain curves of the typical and control specimen results for the FAC 35-30 E specimens. Figure 59 superimposes the two average stress/strain curves of the typical and control specimen results for the Z 5/5-35-30 E specimens. Table D7 also presents the tabulated test results of all these tests. The results indicate only a slightly higher ultimate strength for the control specimens at 13,339 lb/in^2 than for the typical

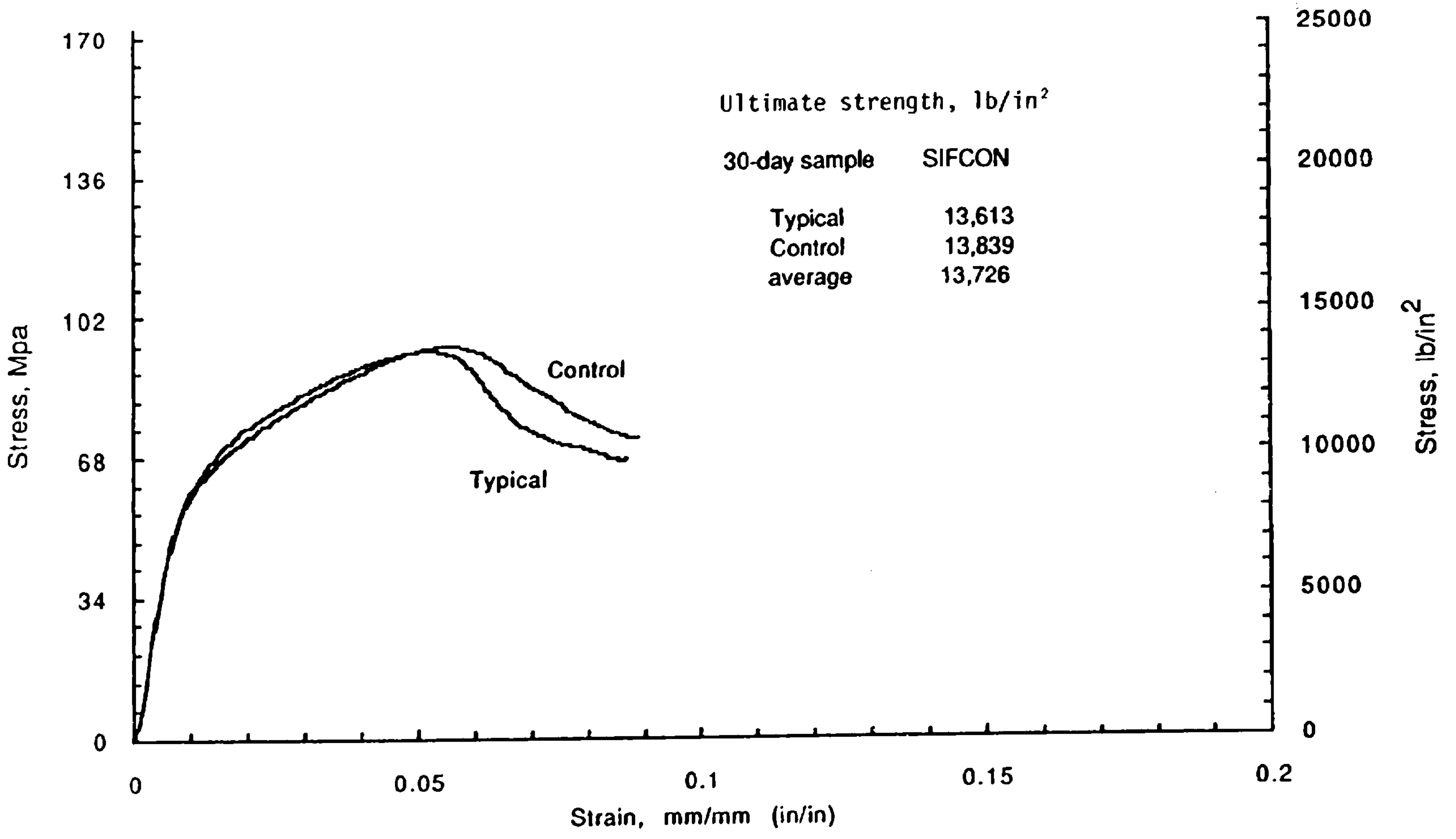


Figure 58. FAC 35-30 E (average) compression.

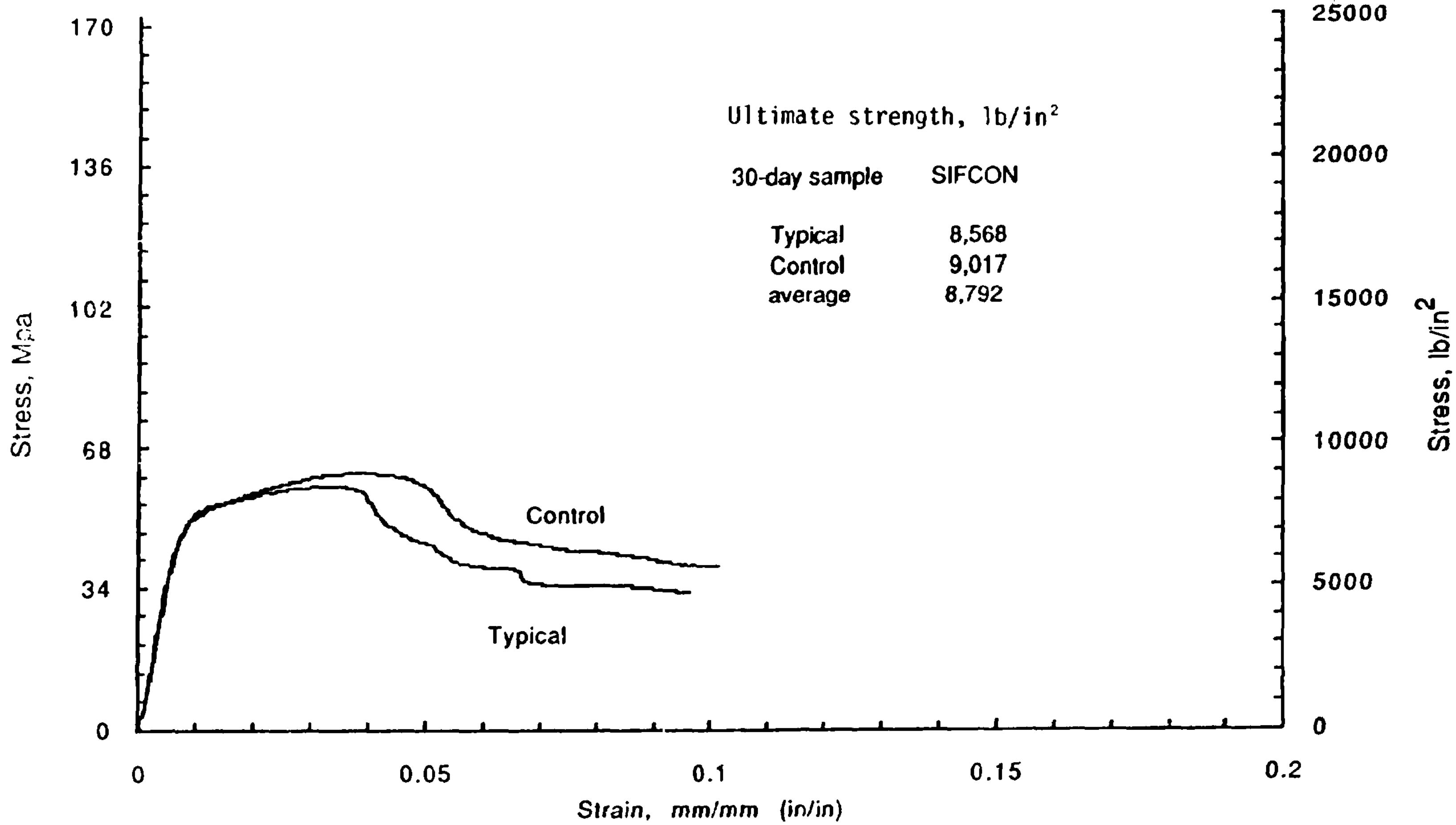


Figure 59. Z 5/5-35-30 E (average) compression.

specimens at 13,613 lb/in^2 for the FAC 35-30 E sets. The results of the Z5/5-35-30 E were a little more pronounced with the control specimens at 9017 lb/in^2 and typical specimens at 8568 lb/in^2. In both comparisons the typical stress-strain curves were consistantly lower than the control curves. The results of the control specimens are comparable to the average of the results of the specimens with identical proportions from the previous program. The results of the FAC 35-30 E control mix were approximately 9 percent higher than the average of the same mixes of the previous program (12,735 lb/in^2). The results of the Z5/5 35-30 E control mix were approximately 4 percent lower than the same mix of the previous program (9359 lb/in^2). Both of these differences are within typical SIFCON variance of test results.

The SIFCON compression results of this program were compared with those of the previous program. Simple ratios were calculated to determine the extent of the differences. Table 4 tabulates the results of these calculations. The parameters of interest here are the V, W, and X ultimate strength ratios. They represent the ratios of present versus previous program test results for 30-day SIFCON, 30-day slurry, and 7-day slurry, respectively. The ratios make it evident that the present program SIFCON results are consistently lower than those of the previous program for all applicable study groups. The slurry results, however, were very close to the same in the two programs. The average ratio for the 30-day SIFCON for all combined tests was 0.785, while the average ratio for both 30- and 7-day slurries was 0.970. This points to a problem in the SIFCON specimens, since the slurries seem to correspond closely in the two programs. These SIFCON ratios can also be used as adjustment factors to get a more realistic estimate of the actual SIFCON strengths for this program.

Conclusion--Initially it was thought that the edge effects were the most significant contributing factor to the lower strengths. In the previous program all core specimens were approximately 1 in from any edge. In this program, cores were approximately 5/8 in away from an edge at the closest point. The test results of this subgroup tend to confirm that this was a major contributing factor.

TABLE 4. STRENGTH COMPARISON SUMMARY

Legend:

S = SIFCON / slurry strength at 30 days
T = 30-day / 7-day strength of slurry
U = 30-day SIFCON / 7-day slurry strength
V = Present / previous program for 30-day SIFCON
W = Present / previous program for 30-day slurry
X = Present / previous program for 7-day slurry
Y = Modulus of rupture / 1st crack strength at 30 days
Z = Compression (adjusted) / modulus of rupture at 30 days

NOTE: All calculations based on ultimate strength values except as noted.

Study Group 1--Water / cement + fly ash

Present program compression compared				Previous program compared			Flexure compared	
Identification	S	T	U	V	W	X	Y	Z
Minimum	1.17	1.10	1.49	0.70	0.95	0.88	1.45	2.38
Maximum	1.93	1.60	2.41	0.90	1.04	1.40	1.80	3.65
Average	1.45	1.37	1.92	0.77	1.00	1.09	1.64	2.88

Study Group 2--Fly ash / cement

Identification	S	T	U	V	W	X	Y	Z
Subgroup 2a (W / C + FA = 0.30)								
Minimum	1.23	1.37	1.69	0.70	0.86	0.79	1.62	2.74
Maximum	1.27	1.44	1.82	0.87	1.09	1.05	2.26	4.09
Average	1.26	1.41	1.76	0.76	1.01	0.92	1.98	3.59
Subgroup 2b (W / C + FA = 0.35)								
Minimum	1.17	1.10	1.49	0.90	1.01	1.40	1.51	2.56
Maximum	1.98	1.46	2.41	0.90	1.01	1.40	1.80	2.71
Average	1.52	1.31	1.88	0.90	1.01	1.40	1.62	2.64
Subgroup 2c (W / C + FA = 0.40)								
Minimum	1.15	1.26	1.45	0.67	0.85	0.86	1.50	2.41
Maximum	1.59	1.46	2.16	0.99	1.22	1.20	1.88	3.57
Average	1.38	1.36	1.89	0.76	0.99	1.00	1.73	2.95
Subgroups 2a through 2c combined								
Minimum	1.15	1.10	1.45	0.67	0.85	0.79	1.50	2.41
Maximum	1.98	1.58	2.41	0.99	1.22	1.40	2.26	4.09
Average	1.41	1.37	1.87	0.78	1.00	0.99	1.79	3.20

Study Group 3--Fiber types

Identification	S	T	U	V	W	X	Y	Z
Minimum	0.77	1.10	0.97	0.63	0.72	0.78	1.15	2.30
Maximum	1.98	1.46	2.81	1.02	1.03	1.40	2.65	4.82
Average	1.34	1.32	1.83	0.82	0.92	1.00	1.91	3.35

Study Group 4--Sand

Present program compression compared				Previous program compared			Flexure compared	
Identification	S	T	U	V	W	X	Y	Z
Subgroup 4a (Sand types)								
Minimum		1.24						
Maximum		1.56						
Average		1.45						
Subgroup 4b (W / C + FA = 0.30)								
Minimum	1.26	1.09	1.82				1.53	2.80
Maximum	1.83	1.44	2.39				1.72	3.65
Average	1.54	1.32	2.01				1.64	3.10
Subgroup 4c (W / C + FA = 0.40)								
Minimum	1.24	1.34	1.81				1.21	3.17
Maximum	2.08	1.53	3.05				1.83	3.34
Average	1.85	1.43	2.68				1.65	3.22
Subgroups 4a through 4c combined								
Minimum	1.24	1.09	1.81	0.70	0.95	0.88	1.21	2.80
Maximum	2.08	1.53	3.05	0.70	1.04	0.98	1.83	3.65
Average	1.69	1.38	2.34	0.70	0.99	0.93	1.65	3.16

Study Group 7--Edge effects

Identification	S	T	U	V	W	X
Minimum	1.25			0.92	0.90	
Maximum	2.02			1.09	0.90	
Average	1.64			1.01	0.90	

All Mixes Combined

Identification	S	T	U	V	W	X	Y	Z
Minimum	0.77	1.09	0.97	0.63	0.72	0.78	1.15	2.30
Maximum	2.08	1.60	3.05	1.02	1.22	1.40	2.65	4.82
Average	1.45	1.38	2.00	0.79	0.97	0.97	1.81	3.20

Upon closer examination, other factors were observed that would contribute to the strength differential. These factors are also related to this edge effect phenomenon. It was also observed that the fiber percentage of the SIFCON of the present program was consistently lower than that of the previous program. Table 1 shows this comparison. This should have been expected since there is a greater proportion of edge area per total slab volume for the smaller sized slabs. Fewer fibers would result in lower SIFCON strengths because of the decrease in reinforcement.

A third contributing factor was observed. Because of the difference in geometry of the molds of the two programs, there was a tendency for the same fibers to distribute themselves in the mold a little differently. The small molds seemed to confine the fibers and restrict random free distribution. The smaller molds of the present program tended to be less interlocked than the larger molds of the simulation of the previous program. The result was a less dense distribution of fibers. This factor, along with the increased edge area proportion, explains the lower fiber percentage of this present program.

In conclusion, these three factors seem to explain the strength discrepancy. It appears that almost all the SIFCON compression tests of this program are approximately 79 percent lower than those of the previous program. However, these compression tests should not be considered representative of typical SIFCON. It is recommended that molded slabs to be used in coring compression specimens be of such dimensions that the cored cylinders can be removed at least 1 in from any edge. These slabs should be large enough so that the geometry does not restrict a free, random distribution that produces a typical interlocking mat representative of the fibers in large volumes.

Study Group 8--Shear tests

General--The purpose of this study group was to attempt to find an adequate shear test. The scope of this investigation was limited and only one method was scrutinized. Only preliminary data were obtained. Had there been an adequate test method, the material properties of SIFCON in shear would have been investigated. However, no test method has been developed to specifically test SIFCON's shear properties before this attempt.

A midpoint loaded beam or simple deep beam test was selected to determine its adequacy as a shear test. Thirty six test specimens were fabricated using the same procedures as those for the fabrication of flexure test specimens. These beams were made from the two mixes identified as FAC 35-30 S and FAC 35-30 T. These specimens were then tested in shear at varying span lengths and a midpoint load (Fig. 10).

Compression--Compression tests were performed for the two mixes in this group. The results are presented in Table D7 and Figures C86 and C91. The SIFCON ultimate strengths were both lower than that of the average of the mixes with the same mix proportions of subgroup 2b. The slurry strengths were higher than the average of the comparable mixes.

The strengths for the two mixes included 10,434 and 10,253 lb/in^2 for SIFCON, and 8427 and 8780 lb/in^2 for the slurry for FAC 35-30 S and FAC 35-30 T, respectively. The average strengths of the comparable mixes of subgroup 2b included 11,473 lb/in^2 for the SIFCON and 7642 lb/in^2 for the slurry.

Shear--The main purpose of these tests was to determine the adequacy of a particular test configuration for obtaining shear stresses. The tests were performed in two stages. The first stage was performed as a preliminary series for the purpose of making observations or modifications to the test method as needed. The second stage was intended to evaluate the adequacy of the test method. Until a suitable test method could be found, only relative strength values were needed.

The first stage included the shear specimens from the FAC 35-30 T mix. The results of these tests are contained in Figure 60 and are summarized in Table D7. These were all tested using a 4-in bottom support span length and a 4-in beam depth with the load applied in the center of the span length. The first four specimens were tested unrestrained. It was observed that, as the load approached the ultimate strength, the beam supports began to slide away from the cent . This sliding continued until the load was relieved. An attempt was made to restrain this lateral movement of the supports under the next three tests. This was not entirely successful. Again lateral movement began as the load approached the ultimate strength. The last three

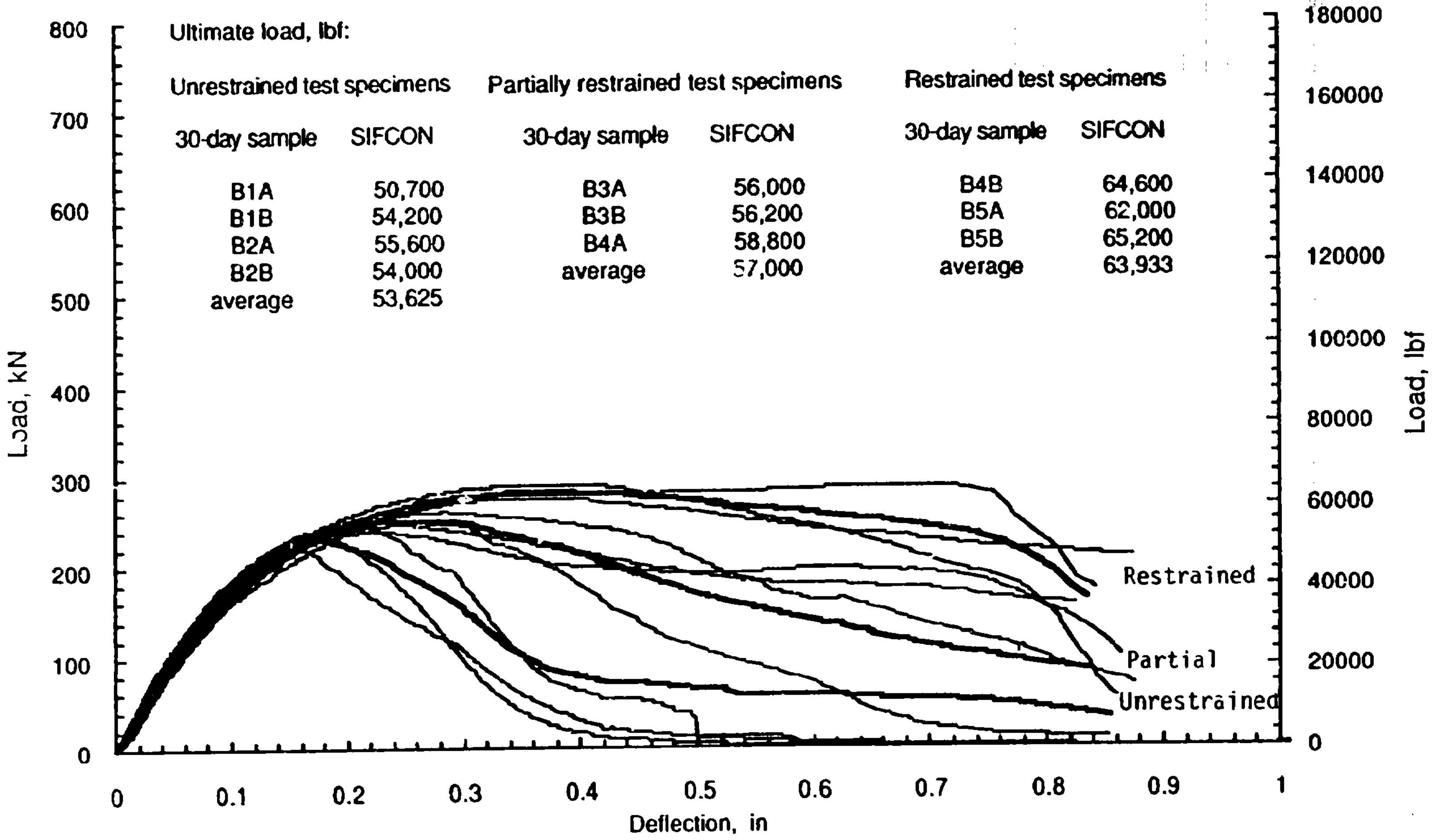


Figure 60. FAC 35-30 T (4-in) shear.

specimens were tested with full restraints on the supports. The effects of these three load conditions are illustrated in Figure 60. When the supports are restrained, the specimens continue to hold a high load over large deflections; while in the case of specimens with supports unrestrained, the tendency is for the load to drop off shortly after reaching the ultimate strength. The specimens with partially restrained supports produce load/deflection curves that track between those of the unrestrained and fully restrained supported specimens. All load/deflection curves tracked one another very closely through the elastic range. The curves begin to deviate from one another at the point where the support begins to slide apart. The ultimate strengths are higher for specimens with restrained supports and lower for those with unrestrained supports.

The second stage included the shear specimens from the FAC 35-30 S mix. The results of these tests are contained in Figure 61, Figures C87 through C90, and Figure 62 and are summarized in Table D7. Figure 61 is representative of Figures C87 through C90. These specimens were all molded as 5-in-depth beams. A deeper beam of 5 in was selected to more closely approximate a shear failure rather than a flexural failure. The span length of these specimens was varied from 4 to 8 in. The load again was applied at the midpoint of the span. Some specimens were tested with supports restrained and others unrestrained. In general the specimens with restrained supports failed at higher loads compared with those of unrestrained supports. The load/deflection curves also deviate similarly to those described in the first stage of this study group. The shape of the curves seems to show similar patterns.

Table D7 summarizes the ultimate loads for these tests. An average shear stress was also calculated. These values should be considered preliminary only, since the test method has not been established. These shear stresses were calculated by dividing the ultimate load by 2 and then dividing by the beam cross-sectional area (depth times width). Figure 62 plots these shear stresses against the varying span lengths. The values decrease at an increasing rate as the span length increases. From the second-order polynomial curve fit, the ultimate shear strengths ranged from 1920 to 1080 lb/in^2 for a range of span lengths of 4 to 8 in, respectively.

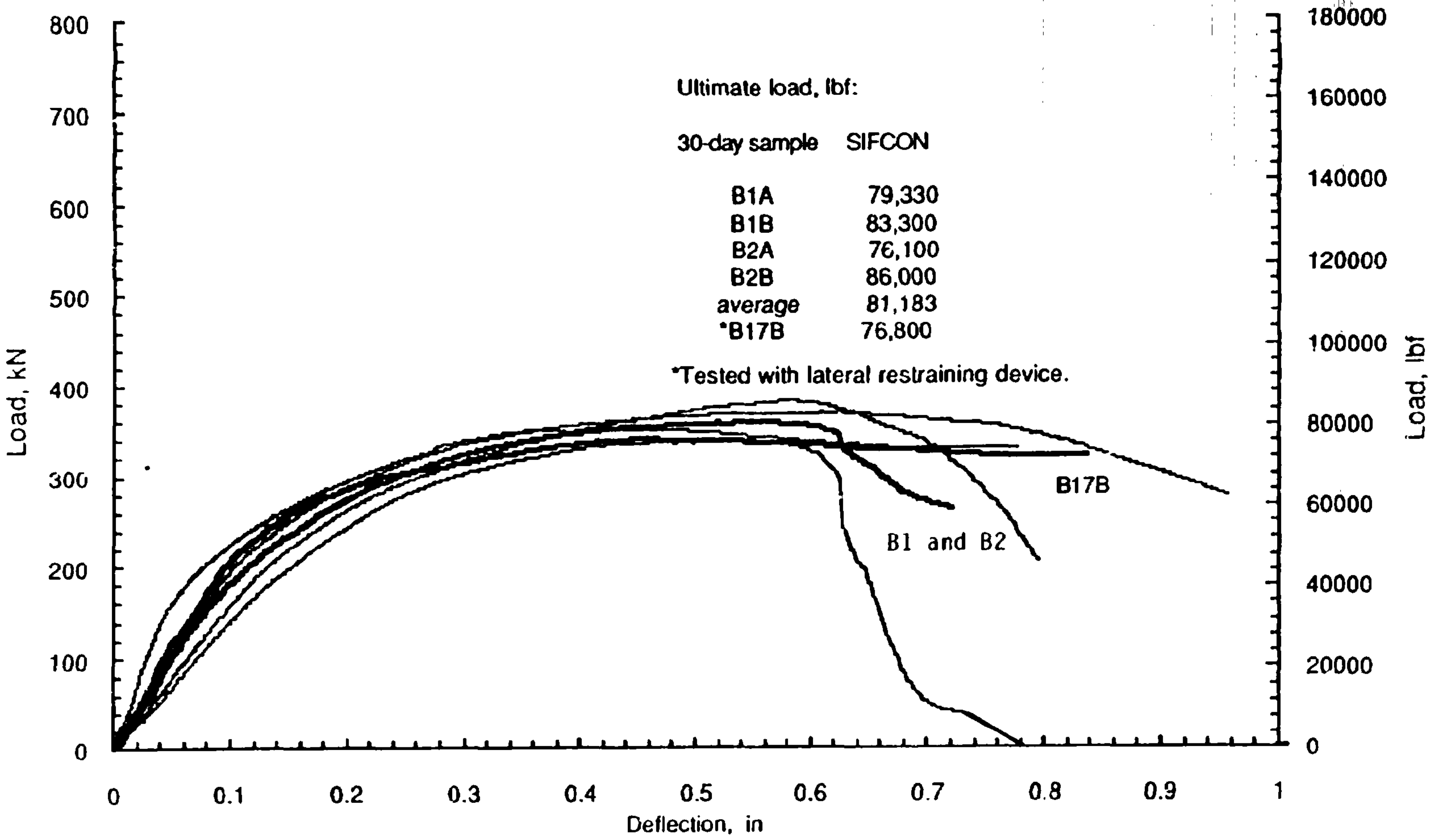


Figure 61. FAC 35-30 S (4-in) shear.

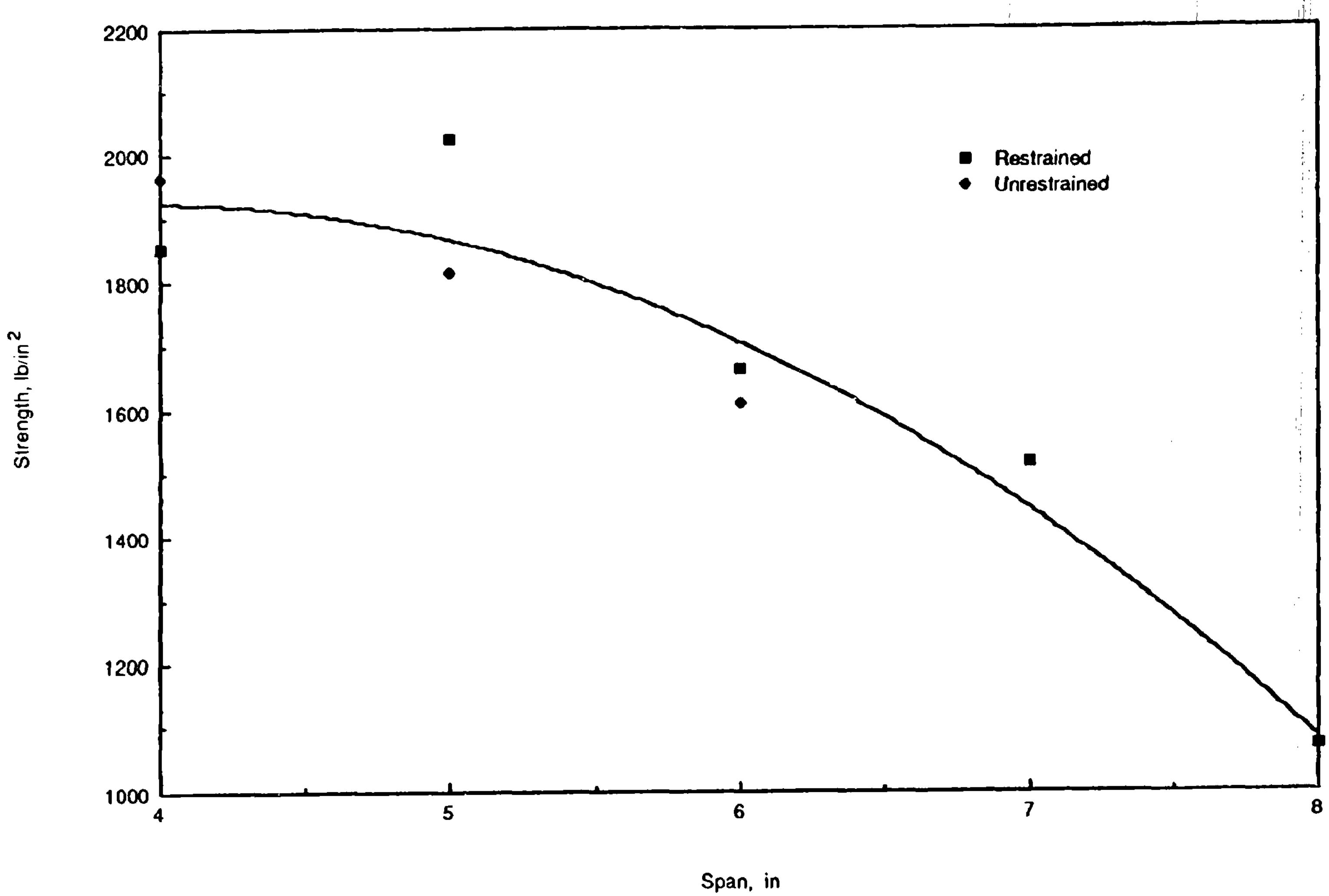


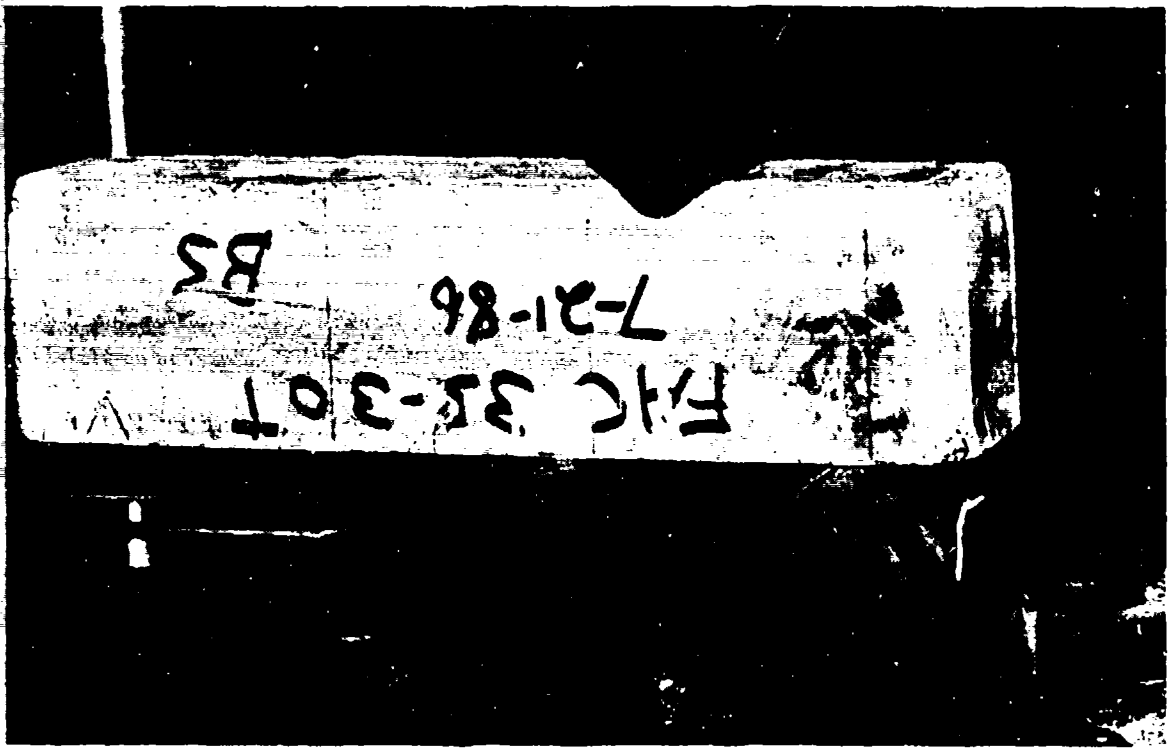
Figure 62. Ultimate average shear stress versus span length (FAC 35-30 S).

Conclusion--The tests performed in this study group were limited. Much more effort is needed to make a definitive conclusion concerning the adequacy of the method used in obtaining shear strengths. The present method that was used--a midpoint loaded beam or simple deep beam--at least needs refinements. The method did give a preliminary indication of SIFCON ultimate shear strength. The general shape of the shear load/deflection curve has now been observed.

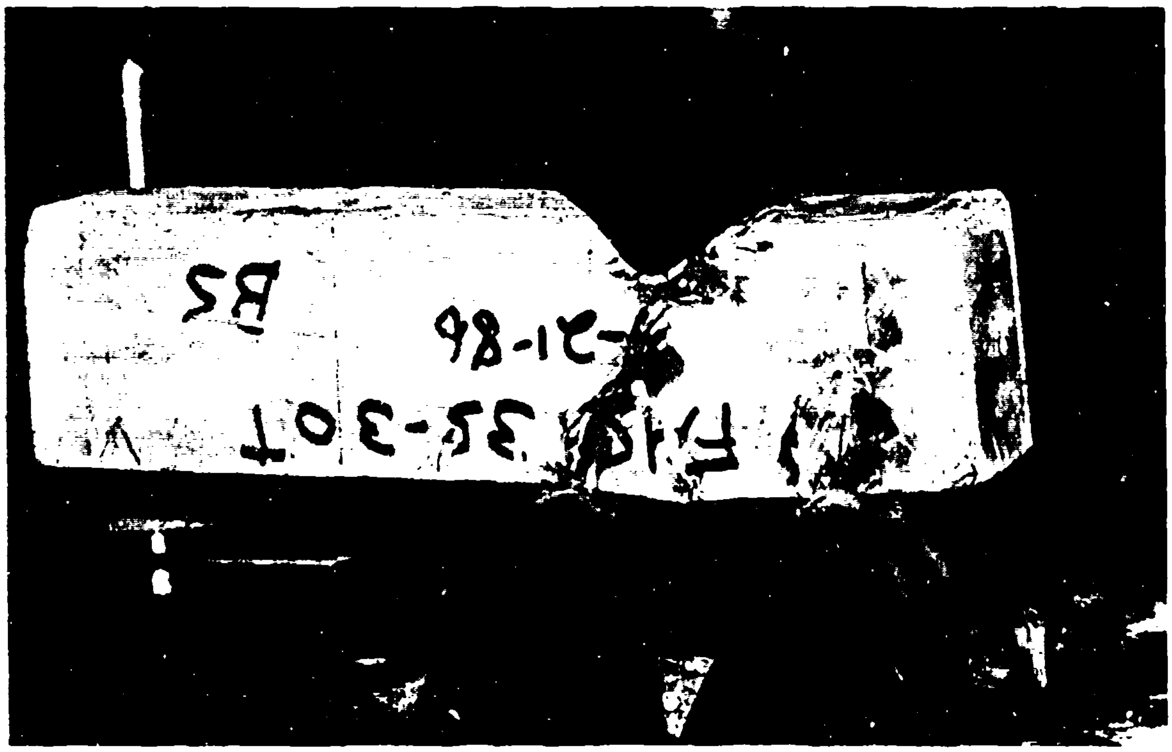
This method does afford some advantages. The specimens required for the test are easy to fabricate; they are very similar to flexure specimens. The test method is very simple to set up. At least for the shorter span lengths, the method did appear to produce the desired shear stresses.

There were some problems encountered with the test method. The tendency of the supports to move away from the center indicates that there were some bending stresses acting on the beam even at a 4-in span length. Better restraining devices need to be developed for this particular method. Another problem was observed after considerable loading. The two supports and the upper loading point cut deep grooves into the specimen. This deformation began to occur just before the peak load was reached and became increasingly deeper as the loading continued. Figure 63 shows the different stages of the shear test. Part a shows the test at initial loading. Part b shows the test at approximately the ultimate load. Part c shows the later stages of the test after considerable deformation. Part d shows the grooves produced by the bearing points after the test had been completed. Since this grooving occurred near the ultimate strength and continued after the ultimate, the effect may not be critical.

From the observations and results of these tests, the following recommendations can be made. Some modifications to and further study of the subject test method are needed. The loading contact point and specimen supports should be manufactured with larger radius contact points. This may minimize the effect of the grooving damage of specimens. Also, a better record of where on the load/deflection curves this grooving begins to occur needs to be noted. The span length of the supports should not exceed 4 in. A shorter span length of the supports should be studied. The supports should be fully restrained.



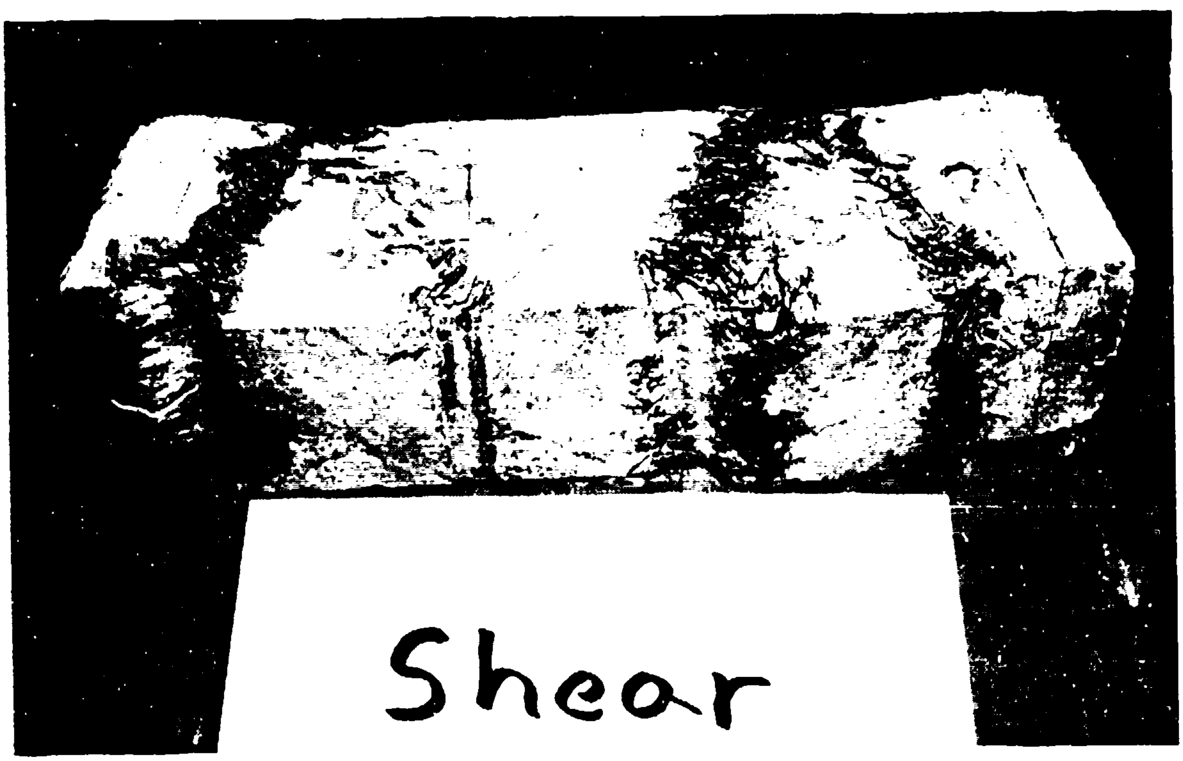
(a) Shear test method.



(b) Shear test at approximately ultimate strength.

Figure 63. Shear test.

(c) Shear test well past ultimate strength.



(d) Typical shear failure mode--two tests and one specimen.

Figure 63. Concluded.

Other types of shear tests should be studied. Figure 64 illustrates two other types of shear test configurations that are possibilities. A punch shear test may also be considered. Test results from each testing device could be compared with one another for consistency.

Study Group 9--Tension tests

General--An attempt was also made to develop an adequate tension test. The scope of this investigation was limited and only one method was scrutinized. Preliminary tension properties were obtained.

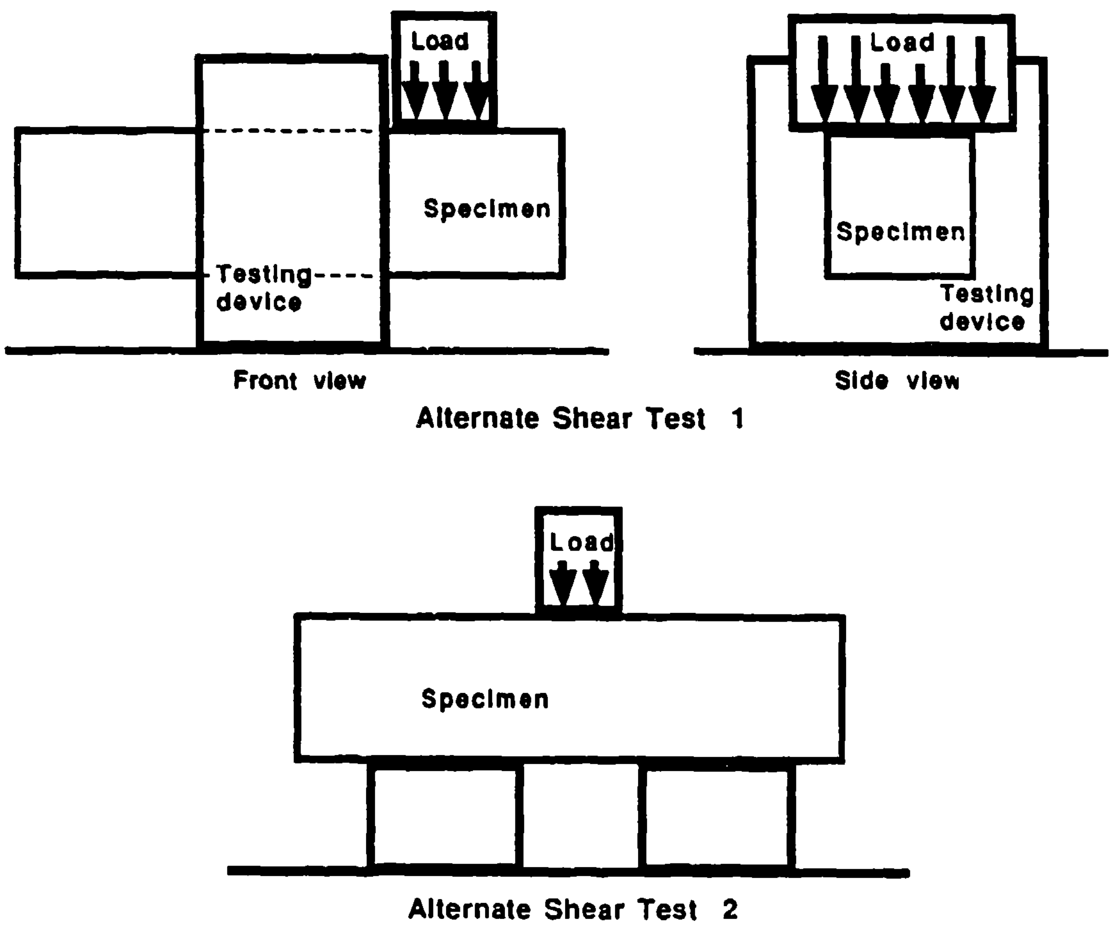


Figure 64. Proposed shear tests.

The major difficulty in developing a tension test is the method used to grip the ends of the specimens. To accomplish this, a special device was developed and specially shaped specimens were manufactured. The testing device and specimens were described earlier. During testing, observations were made concerning the adequacy of the test method. Because a major effort was performed to overcome the specimen edge effects, the major parameter compared was the effects of different notching configurations. All specimens were made from the one mix identified as FAC 35-30 T.

Compression--Compression tests were performed for the mix in this group. The results are presented in Table D7 and Figure C91. The SIFCON ultimate strength for the mix was lower than that of the average mixes with the same mix proportions of subgroup 2b. The slurry strength was higher than the average of the comparable mixes. The strengths for the mix were 10253 lb/in^2 for SIFCON and 8780 lb/in^2 for the slurry. The average strengths of the comparable mixes of subgroup 2b included 11,473 lb/in^2 for the SIFCON and 7642 lb/in^2 for the slurry.

Tension--A test method was studied that would not only produce tension stresses but also produce failure in the desired location of a specimen. In general, tension specimens tend to fail at the gripping devices of the test unless some mechanism is designed into the method to cause failure in a desired area away from the devices. To accomplish this, a specially shaped specimen was designed along with a compatible testing device. Figure 11 illustrated the specimen and the testing device. The specimen was designed with a reduced cross-sectional area in the middle portion. The testing device was set to bear on the larger portion of the specimen. The specimen was also notched by saw-cutting grooves at various intervals in the reduced cross-sectional area (Figs. 7 and 8). The intervals ranged from 2 to 0 in (milled specimens). The purpose of this notching was to eliminate the edge effects of the molded surfaces. The reason notches were at different intervals was to study possible stress concentrations produced as a result of the notching.

Tension stresses were calculated by taking the load values obtained during testing and dividing by the smallest measured cross-sectional area of the specimen. This smallest cross-sectional area was used even when failure occurred at larger cross-sectional areas in the specimen.

Since deflections of the testing machine load platen were measured instead of deflections within a gage length, there was no actual gage length to calculate strain values. Therefore the strains were calculated by dividing the deflections by an arbitrary 7-in gage length for all tests. This was the maximum length of the reduced cross-sectional area of the specimens. Therefore, all strain values are only relative. For the purpose of this study, only relative values of both stress and strain were needed.

Figures 65 and C92 through C96 present the individual stress/strain curves for these tests. Figure 65 is representative of the others. The ultimate strengths of the different notched conditions vary, but the shapes of each of the curves are very similar. Table D7 summarizes the average ultimate strengths for the various notched conditions. These ultimate strengths showed no discernible patterns. Initially it was expected that the highest stresses would be displayed by the milled specimens with the least possibility for stress concentrations. It was also expected that the lowest stress would be displayed by the widest spacing of notches. After actual testing, the opposite results were obtained. The stresses ranged from 1151 to 1691 lb/in^2 for the milled specimens and for the 2-in notched specimens, respectively. The variation within each notched group was very high. The average of all the specimens was 1414 lb/in^2, also with a high variation. All these values should be considered very preliminary.

The failure modes of the specimens within each notched group showed no discernible patterns. Some specimens failed in the center at the smallest cross-sectional area, as desired, while others failed near the testing device bearing location. The rest of the specimens failed at locations between those two extremes. In summary, all these results indicate a very high variability in tension results for the method used.

After reviewing the results, it was realized that a set of specimens with no notches should have been prepared and tested. This may have indicated the value of notching specimens and the severity of edge effects in tension specimens.

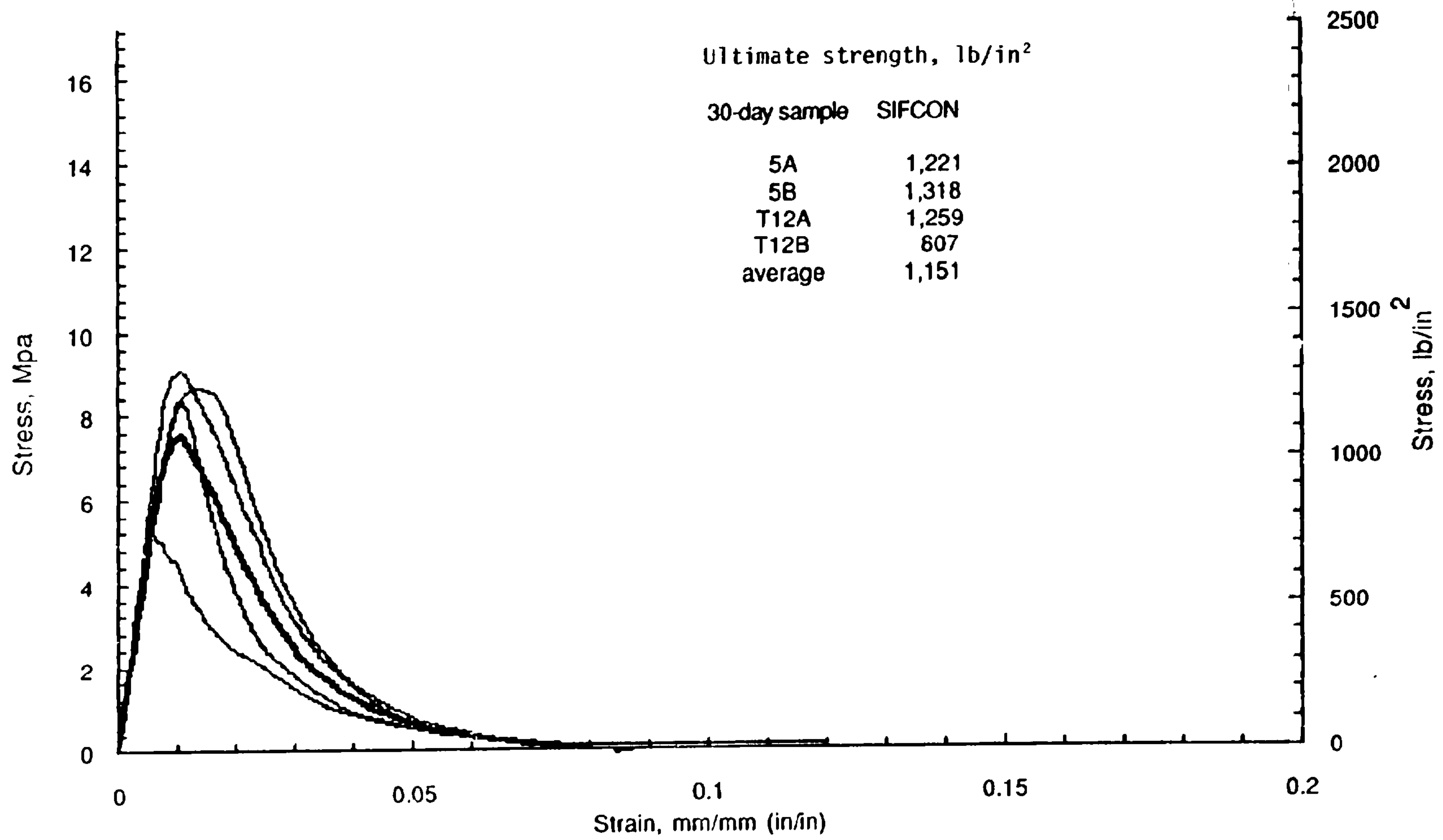


Figure 65. FAC 35-30 T (milled) tension.

Conclusion--This study group revealed the general characteristics of SIFCON when tested in tension. The test method and the type of test specimen used appeared to be adequate, although some modifications could be made. A preliminary indication of SIFCON ultimate tensile strength for the particular fibers and mix ingredients used was obtained. The general shape of the tension stress/strain curve has been observed. Therefore these few tests have given much new data concerning SIFCON material properties.

It is recommended that the test method be studied further. A set of specimens should be tested comparing the difference in results of notching and not notching specimens. If there is a negligible effect, then notching should be eliminated. This would greatly reduce the effort and cost of preparing tension specimens. Attempts should be made to minimize the large variation in ultimate strength test results. All tests in this group should be repeated to study the consistency of the results. Finally, since the primary effort of this study group was to test the adequacy of a test method, there is much that can be done to study the material properties of SIFCON in tension. The mix ingredients can be varied as in the other study groups of this program.

PARAMETER COMPARISON

In actual use of materials, it is impractical to perform tests to determine every strength parameter. It is useful to develop relationships between parameters. If relationships can be developed by knowing selected parameters, then other parameters can be calculated using these relationships. An attempt was made to accomplish this in this program. Table 4 (a condensation of Table D9) compares the strengths of various parameters in terms of simple ratios. The table summarizes eight ratios for each of the major study groups. The legend in the table explains the specific ratios calculated. The ratios were generated using data from Tables D1 through D8. Other ratios could be generated in a similar fashion using the other data from Tables D1 through D8.

Table 4 also clearly shows the discrepancy between the tests performed in the previous program and those of this program. This discrepancy was discussed in the treatment of the results of Study Group 7.

Because of this difference in test results, a decision was made in the calculation of the Z-ratio. The Z-value represents the ratio of 30-day SIFCON compression to the 30-day SIFCON modulus of rupture. From the observations and results of Study Group 7, it was determined that the SIFCON compression values obtained in the previous program were more representative than those of this program. Therefore an adjustment was made to the SIFCON compression results of the present program. The adjustment in essence increased the compression results of the present program to the level of the results of the previous program. This was accomplished by dividing the individual V-value into the compression result of the present program and then dividing this value by the modulus of rupture test results. Whenever there was no V-value, because of no corresponding test in the previous program, the average value of all combined V-values was used (0.785). The end product of this adjustment should be a more representative indication of the simple ratio relationship of the ultimate flexure strength and the ultimate compressive strength.

The values in the table may be useful in several ways. They could be used in estimating untested parameters when only a few easy-to-test parameters are known. They could be used in the design of SIFCON mixes when a desired parameter is specified. These ratios should be used only as general indicators. In using them, the range of values obtained should be kept in mind.

Table 4 not only contains individual ratios for each mix, but also minimum, maximum, and average values organized according to the study groups and subgroups. An overall program tabulation of minimums, maximums, and averages is presented at the end of the table. Important ratios to note include an average value of 1.4 for the ratio of compression ultimate strength of 30-day SIFCON to 30-day slurry, 1.8 for the 30-day flexure modulus of rupture to 30-day first crack strength, and 3.2 for the ratio of adjusted compression ultimate strength for 30-day SIFCON to 30-day flexure modulus of rupture.

IV. PROGRAM CONCLUSIONS AND RECOMMENDATIONS

MAJOR CONCLUSIONS

The first SIFCON program demonstrated that, in general, the variables that affect conventional concrete material properties have an analogous effect on SIFCON compressive strength. SIFCON in flexure also displays material properties that are analogous to those of SIFCON in compression.

This second program investigated many of the same variables that were investigated in the previous program. Mixes were fabricated that varied most of the SIFCON ingredients individually. One area of investigation that was different from the one in the previous program was a study of the effects of adding fine-grained sands to SIFCON mixes. All these mixes were tested not only in flexure but also in compression. These test results revealed the flexure material properties and also provided a correlation between the two programs.

Table 5 summarizes the flexure material properties developed in this program. The fluidity and compression material properties parallel those of the previous program. The compression strength results, however, were lower in this program. The explanation for this related to a faulty procedure in the molding of the specimens. Concerning the flexural properties, in general, the flexure strengths increase as the water-to-cement plus fly ash ratio is decreased or as the cement content is increased. For these two variables a range of flexure strengths of 2058 to 5792 lb/in^2 was obtained. The effects of varying different fiber types must be reviewed individually within the particular fiber type. Because of the many variables, no general trends can be concluded. The use of sand in SIFCON tends to enhance not only the compressive but also the flexural strength properties. Further studies should be performed to increase the fluidity and workability of sand slurries.

A few studies were performed that were designed to examine test methods. The composite beam tests were only partially successful but gave preliminary data that could be used if this area is examined further. The variable depth beam tests tended to verify that the flexural test method

TABLE 5. FLEXURE PROGRAM TEST RESULTS SUMMARY

Study Groups, As the following variables decrease:	Viscosity		SIFCON compressive strength	Modulus of rupture	1st crack strength	Modulus of elasticity	1st crack toughness	Toughness indices			Toughness ratios	
	Flow	Open time						I_5	I_{10}	I_{30}	$I_{10/5}$	$I_{30/10}$
Group 1 : W/C + FA	+	-	+	+	+	?	+	-	-	-	+	+
Group 2 : FA/C + FA												
2a : FA/C + FA – (W/C + FA = 0.30)	-	+	+	+	+	+	?	-	-	-	+	+
2b : FA/C + FA – (W/C + FA = 0.35)	=	=	=									
2c : FA/C + FA – (W/C + FA = 0.40)	-	+	+	+	+	+	+	-	-	+	+	+
Group 3 : Fiber types	=	=	?	?	?	?	?	?	?	?	?	?
Group 4 : Sand												
4a : Sand types	-	+										
4b : Sand – (W/C + FA = 0.30)	-	+	-	-	-	-	?	-	-	-	+	+
4c : Sand – (W/C + FA = 0.40)	-	+	+	+	+	+	+	-	-	+	+	+
Group 5 : Depth of SIFCON -- composite beams			=	-	-							
Group 6 : Span/depth -- variable depth beams			=	+	+	+	+	?	?	?	?	?

Notes :
+ refers to a corresponding increase.
- refers to a corresponding decrease.
= refers to no variable involved for this parameter.
? refers to no conclusion can be drawn from the data.

used was acceptable. The edge effects study revealed a flaw in the compression specimen fabrication of this program. This explains the lower compression results of this program compared to the previous program. The shear test method study was partially successful and needed more investigation. The tension test method study was acceptable but needed refinement. All these studies require further examination to assure complete confidence in the acceptability of the test methods.

The data acquisition and reduction procedures of this program were improved, streamlined, and further computerized over those of the previous program. The results were not only more accurate but were also easier to analyze.

RECOMMENDATIONS

All the problems encountered in the previous program were corrected in this program. But since this program still involved further research, other problems were encountered that should be corrected. Overall, the general procedures used in this program were very adequate. They can be recommended for use in other SIFCON programs.

One major problem, however, must be avoided. The size of slabs used in the fabrication of compression specimens must be carefully designed. A slab prepared for removing cores must be large enough so that these core specimens can be removed with no edge effects, and also large enough so that the fibers freely distribute themselves in the mold in a random manner representative of large SIFCON masses.

The recommendations relating to the variable study groups are few. The flexural results varying the slurry ingredients were successful. However, since these were essentially first-time tests, they should be verified. The results should also be refined. In each of the first two study groups, only selected mixes were tested. Many other mixes could be tested. The fiber-type study group needs much further examination. In this study group there are unanswered questions relating to (1) the adequacy of test methods for some of the fiber types, (2) the many variables within the fiber types themselves, and (3) the flexure material properties. Much further study is also needed concerning the use of sands in slurries.

Since sands not only enhance the SIFCON slurry matrix and show excellent prospects of economy in their use, an entire program devoted to sands is warranted. Only very selected studies were performed here.

Much more effort is recommended for the test method study groups. First, the usefulness of the composite beams in modeling must be evaluated before any further study can be justified. Second, of the value of saw-cutting the top surface of flexure and shear specimens needs study. Such a study should be performed to see if such a procedure is really needed. Third, this program did not satisfactorily establish an adequate shear test; there is therefore need for further work in this area. An entire program is warranted not only for the development of an adequate test method but also for the shear material properties. A similar recommendation can be made for tension tests.

Other types of material properties tests should be considered for future SIFCON programs. A good list of such further studies was recommended in the previous program (Ref. 1, pp. 72-74).

REPORT CONCLUSION

Another step has been completed in the quest to understand SIFCON material properties. This program and the previous one show that SIFCON has great potential as a construction material. It is hoped that the more that is understood about SIFCON, the more confidence engineers and construction people will have in it, and the more they will use their creativity in finding applications for it.

APPENDIX A
MIX DESIGNS

This appendix (Tables A1-A9) presents the mix designs used for each separate study group. As shown, some mixes occur in more than one study group. Every mix produced was given a distinct identification code. When a second mix of the same proportions as a previous one was made, the identification code was similar but was distinguished by a different letter designation at the end. The mix design tables include all mix ingredients and proportions. The tabulated weights are those of the actual laboratory-mixed batches.

TABLE A1. STUDY GROUP 1-- WATER/CEMENT + FLY ASH MIX DESIGNS
(Compression and Flexure Tests)

Constants:	Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
	Fly ash/cement:	30/70 ± 0.60 by weight (except as noted)
	Superplasticizer:	30 ± 0.40 oz/100 wt (cement + fly ash)
Variables:	Water/cement + fly ash	

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, [a] cm^3	Water/ cement + fly ash	Water/ cement
CW 28-30	110.86	47.51	43.55	[b]1705	0.275	0.393
FAC 30-30 F	106.61	45.69	45.69	1350	0.300	0.429
CW 33-30	102.68	44.01	47.67	1300	0.325	0.464
FAC 35-30 C	233.33	100.00	116.67	2955	0.350	0.500
FAC 35-30 D	310.00	132.86	155.00	3930	0.350	0.500
FAC 35-30 E	105.80	45.34	52.90	1340	0.350	0.500
FAC 35-30 F	270.07	115.75	135.04	3425	0.350	0.500
FAC 35-30 S	270.07	115.75	135.04	3425	0.350	0.500
FAC 35-30 T	270.09	115.75	135.04	3425	0.350	0.500
Z 3/5-35-30 F	275.08	118.39	137.54	3485	0.350	0.500
CW 38-30	119.53	51.23	64.03	1515	0.375	0.536
FAC 40-30 F	93.00	41.00	56.00	1170	0.400	0.602
CW 43-30	111.85	47.93	67.91	1420	0.425	0.607

[a] The weights and measures contained in all the mix design tables are presented in the actual values and units measured by the laboratory technicians. Therefore there is an inconsistency in the use of English units (lb) and metric units (cm^3). (1 oz= 29.57 cm^3)

[b] Superplasticizer = 36.495 oz/100 wt.

TABLE A2. STUDY GROUP 2-- FLY ASH/CEMENT MIX DESIGNS
(Compression and Flexure Tests)

Constants:	Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
	Superplasticizer:	30 ± 0.40 oz/100 wt (except as noted)
Variables:	Fly ash/cement:	0/100 to 80/20
	Water/cement:	0.30 to 2.00
	Water/cement + fly ash:	0.30, 0.35, 0.40

Mix proportions:

Subgroup 2a
(Water/cement + fly ash = 0.30 ± 0.00004)

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Water/ cement	Fly ash/ cement
FAC 30-0 F	160.99	0.00	48.30	1430	0.30	0/100
FAC 30-10 F	142.19	15.80	47.40	1400	0.33	10/90
FAC 30-30 F	106.61	45.69	45.69	1350	0.43	30/70
FAC 30-50 F	73.51	73.51	44.11	1305	0.60	50/50
FAC 30-80 F	27.95	111.80	41.92	[a]1540	1.50	80/20

Subgroup 2b
(Water/cement + fly ash = 0.35 ± 0.0009)

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Water/ cement	Fly ash/ cement
FAC 35-30 C	233.33	100.00	116.67	2955	0.50	30/70
FAC 35-30 D	310.00	132.86	155.00	3930	0.50	30/70
FAC 35-30 E	105.80	45.34	52.90	1340	0.50	30/70
FAC 35-30 F	270.07	115.75	135.04	3425	0.50	30/70
FAC 35-30 S	270.07	115.75	135.04	3425	0.50	30/70
FAC 35-30 T	270.09	115.75	135.04	3425	0.50	30/70
Z 3/5-35-30 F	275.08	118.89	137.54	3485	0.50	30/70

Subgroup 2c
(Water/cement + fly ash = 0.40 ± 0.00002 except as noted)

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Water/ cement	Fly ash/ cement
FAC 40-0 F	138.55	0.00	55.42	1230	0.40	0/100
FAC 40-10 F	122.00	15.00	[b]58.00	1210	0.475	10/90
FAC 40-30 F	93.00	41.00	[c]56.00	1170	0.60	30/70
FAC 40-50 F	64.04	64.04	51.23	1135	0.80	50/50
FAC 40-80 F	24.50	98.02	49.01	1085	2.00	80/20

[a] Superplasticizer = 37.355 oz/100 wt.
[b] W/C + FA = 0.423
[c] W/C + FA = 0.418

TABLE A3. STUDY GROUP 3-- FIBER TYPES MIX DESIGNS
(Compression and Flexure Tests)

Constants:	Water/cement + fly ash:	0.35 ± 0.00089
	Fly ash/cement:	30/70 ± 0.177
	Superplasticizer:	30 ± 0.092 oz/100 wt
Variables:	Fiber types:	Dramix, Xorex, Fibercon (Table 2)

Mix proportions:

Mix identification code	Fiber type	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	SIFCON loading, %
Z 3/4-35-30 F	ZL 30/40	247.57	106.10	123.78	3135	8.0
OL 35-30 F	OL 20/25	(same slurry as Z 3/4-35-30 F)				6.9
FB 35-30 F	Fibercon 1 in	(same slurry as Z 3/4-35-30 F)				6.9
Z 3/5-35-30 F	ZL 30/50	275.08	117.89	137.54	3485	9.6
X 22-35-30 F	Xorex II/1 1/2 in	(same slurry as Z 3/5-35-30 F)				13.5
Z 5/5-35-30 F	ZL 50/50	275.08	117.89	137.54	3485	5.8
X 11-35-30 F	Xorex I/1 in	(same slurry as Z 5/5-35-30 F)				18.9
Z 6/8-35-30 F	ZL 60/80	275.08	117.89	137.54	3485	7.7
X 21-35-30 F	Xorex II/1 in	(same slurry as Z 6/8-35-30 F)				21.4
X 12-35-30 F	Xorex I/2 1/2 in	211.60	90.68	105.80	2680	5.8
Z 5/5-35-30 E	ZL 50/50	105.80	45.34	52.90	1340	5.8

Note: The following mix designs are a part of this study group: FAC 35-30 C, D, E, F, S, and T.

TABLE A4. STUDY GROUP 4-- SAND MIX DESIGNS
(Compression and Flexure Tests)

Constants:	Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
	Fly ash/cement:	30/70 ± 0.597
	Superplasticizer:	30 ± 0.159 oz/100 wt
Variables:	Sand types:	Brick sand, plaster sand, blasting sands
	Sand/cement:	0 to 200 percent
	Water/cement + fly ash:	0.30, 0.35, 0.40

Mix proportions:

Subgroup 4a--Sand types

Constants:	Cement:	80.00 lb
	Fly ash:	34.29 lb
	Water:	40.00 lb
	Superplasticizer:	1015 cm^3
	W/C +FA:	0.35

Mix identification code	Sand type	Sand, lb	Sand/cement + fly ash, %	Sand/cement, %
S1-X-35-30	Brick sand			
S2-X-35-30	Plaster sand			
S3-X-35-30	Coarse blasting sand			
S4-X-35-30	Medium blasting sand			
S5-X-35-30	Fine blasting sand			
SX-0-35-30	(Sand added to 20 lb of slurry from each of the above mixes)	0.00	0	0.0
SX-25-35-30		3.64	25	35.7
SX-50-35-30		7.28	50	71.4
SX-75-35-30		10.93	75	107.2
SX-100-35-30		14.57	100	142.8
SX-125-35-30		18.21	125	178.5
SX-150-35-30		21.85	150	214.2

Notes:
1. Only slurry cubes were molded for this subgroup.
2. The slurry cubes of the following mix designs are a part of this subgroup: FAC 35-30 C, D, E, F, S, and T; and Z 3/5-35-30 F.
3. The mix identification codes of this subgroup are misleading. They indicate a lower sand percentage than actually present. Refer to the last two columns in this table.

TABLE A4. CONCLUDED

Subgroup 4b--Brick Sand Proportions

(Water/cement + fly ash = 0.30 ± 0.0021)

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Sand, lb	Sand/cement, %
FAC 30-30 F	106.61	45.69	45.69	1350	0.00	0
S 25-30-30 F	99.95	42.84	42.84	1265	24.99	25
S 50-30-30 F	88.84	38.08	38.35	1125	44.42	50
S 75-30-30 F	79.96	34.27	34.27	1015	59.97	75

Subgroup 4c--Brick Sand Proportions

(Water/cement + fly ash = 0.40 ± 0.0085)

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Sand, lb	Sand/cement, %
FAC 40-30 F	93.00	41.00	53.00	1170	0.00	0
S 50-40-30 F	79.24	33.96	45.52	1005	39.62	50
S 100-40-30 F	69.34	29.72	40.04	880	69.34	100
S 150-40-30 F	60.29	25.84	35.00	765	90.44	150
S 200-40-30 F	55.47	23.77	32.37	705	110.94	200

TABLE A5. STUDY GROUP 5-- COMPOSITE BEAMS MIX DESIGNS
(Compression and Flexure Tests)

Constants:

Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
Water/cement + fly ash:	0.35 ± 0.00001
Fly ash/cement:	30/70 ± 0.00001 by weight
Superplasticizer:	30 ± 0.021 oz/100 wt (cement + fly ash)

Variable: Fiber depth (Figure 6)

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Fiber depth, in	Slurry depth, in
FAC 35-30 C	233.33	100.00	116.67	2955	4.0	4
FAC 35-30 F	270.07	115.75	135.04	3425	4.0	4
C 3-35-30 F	Same slurry as FAC 35-30 F				3.0	4
C 2-35-30 F	Same slurry as FAC 35-30 F				2.0	4
C 1.5-35-30 F	Same slurry as FAC 35-30 C				1.5	4
C 1-35-30 F	Same slurry as FAC 35-30 C				1.0	4
C 0.5-35-30 F	Same slurry as FAC 35-30 C				0.5	4
C 0-35-30 C	Same slurry as FAC 35-30 C				0.0	4
C 0-35-30 F	Same slurry as FAC 35-30 F				0.0	4

TABLE A6. STUDY GROUP 6-- VARIABLE DEPTH BEAMS MIX DESIGNS
(Compression and Flexure Tests)

Constants:

Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
Water/cement + fly ash:	0.35 ± 0.000002
Fly ash/cement:	30/70 ± 0.0005 by weight
Superplasticizer:	30 ± 0.011 oz/100 wt (cement + fly ash)

Variable: Span-length to beam-depth ratio

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3
FAC 35-30 D	310.00	132.86	155.00	3930

Note: The slurry cubes of the following mix designs are a part of this subgroup: FAC 35-30 C, D, E, F, S, and T; and Z 3/5-35-30 F.

TABLE A7. STUDY GROUP 7-- EDGE EFFECTS STUDY MIX DESIGNS
(Compression Test)

Constants:	Fiber:	Dramix ZL 30/50 and 50/50, 9.6 and 5.8 percent (Table 2)
	Water/cement + fly ash:	0.35 ± 0.000007
	Fly ash/cement:	30/70 ± 0.0013 by weight
	Superplasticizer:	30 ± 0.017 oz/100 wt (cement + fly ash)

Study: Edge effects of small versus large specimen slabs

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3
FAC 35-30 E	105.80	45.34	52.90	1340
Z 5/5-35-30 E	Same slurry as FAC 35-30 E			

TABLE A8. STUDY GROUP 8--SHEAR TESTS MIX DESIGNS

Constants:	Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
	Water/cement + fly ash:	0.35 ± 0.00001
	Fly ash/cement:	30/70 ± 0.001 by weight
	Superplasticizer:	30 ± 0.021 oz/100 wt (cement + fly ash)

Study: Test methods for testing SIFCON in shear

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3
FAC 35-30 S	270.07	115.75	135.04	3425
FAC-35-30 T	270.09	115.75	135.04	3425

TABLE A9. STUDY GROUP 9--TENSION TESTS MIX DESIGNS

Constants:	Fiber:	Dramix ZL 30/50, 9.6 percent by volume (Table 2)
	Water/cement + fly ash:	0.35 ± 0.00001
	Fly ash/cement:	30/70 ± 0.0005 by weight
	Superplasticizer:	30 ± 0.019 oz/100 wt (cement + fly ash)

Study: Test methods for testing SIFCON in tension

Mix proportions:

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3
FAC-35-30 T	270.09	115.75	135.04	3425

APPENDIX B

FLOW MEASUREMENTS

This appendix presents in Table B1 tabulations of all flow measurements for each of the mix designs. The top of Table B1 shows the times (in minutes) when measurements were taken. These times are with respect to the time when ingredient mixing began (T = 0). The tabulated numbers within the table are the flow measurements in seconds. The vertical lines represent the limits of practical open times (flow = 50 s).

TABLE B1. FLOW MEASUREMENTS

Study Group 1--Water / cement + fly ash

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
CW 28-30	Thick							
FAC 30-30 F	87	Thick						
CW 33-30	36	84	Thick					
FAC 35-30 C	19	24	28	35	55	82	160	
FAC 35-30 D	18							
FAC 35-30 E	20	32		80	120			
FAC 35-30 F	21	27	36	49	140			
FAC 35-30 S	23			93	Thick			
FAC 35-30 T	20		38	64	130			
Z3/5-35-30 F	26	64	72	84	Thick			
CW 38-30	14	16	22	27	41	47	95	191
FAC 40-30 F	14	15	16	18	22	31	47	68
CW 43-30	17	12	14	16	14	15	17	

Study Group 2--Fly ash / cement
Subgroup 2a (W / C + FA = 0.30)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
FAC 30-0 F	36	43	44	43	47	50	53	
FAC 30-10 F	65	67	82	104				
FAC 30-30 F	87	Thick						
FAC 30-50 F	Thick							
FAC 30-80 F	71							

Subgroup 2b (W / C + FA = 0.35)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
FAC 35-30 C	19	24	28	35	55	82	160	
FAC 35-30 D	18							
FAC 35-30 E	20	32		80	120			
FAC 35-30 F	21	27	36	49	140			
FAC 35-30 S	23			93	Thick			
FAC 35-30 T	20		38	64	130			
Z3/5-35-30 F	26	64	72	84	Thick			

TABLE B1. CONTINUED

Subgroup 2c (W / C + FA = 0.40)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
FAC 40-0 F	14	15	15	15	16	17		
FAC 40-10 F	13	14	14	15	18	13	13	13
FAC 40-30 F	14	15	16	18	22	31	47	68
FAC 40-50 F	11	23	52	171				
FAC 40-80 F	12	Thick						

Study Group 3--Fiber types

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
Z3/4-35-30 F	16	28	43	171				
OL 35-30 F								
FB 35-30 F								
Z3/5-35-30 F	26	64	72	84	Thick			
X22-35-30 F								
FAC 35-30 C	19	24	28	35	55	82	160	
FAC 35-30 D	18							
FAC 35-30 E	20	32		80	120			
FAC 35-30 F	21	27	36	49	140			
FAC 35-30 S	23			93	Thick			
FAC 35-30 T	20		38	64	130			
Z5/5-35-30 F	20		57	109				
X11-35-30 F								
Z6/8-35-30 F	26	78 (T=40)		128				
X21-35-30 F								
X12-35-30 F	22	127						
Z5/5-35-30 E								

Study Group 4--Sand
Subgroup 4a (Sand types)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
Comparison Slurry								
FAC 35-30 C	19	24	28	35	55	82	160	
FAC 35-30 D	18							
FAC 35-30 E	20	32		80	120			
FAC 35-30 F	21	27	36	49	140			
FAC 35-30 S	23			93	Thick			
FAC 35-30 T	20		38	64	130			
Z 3/5-35-30 F	26	64	72	84	Thick			

TABLE B1. CONTINUED

Subgroup 4a Continued

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
Brick Sand								
S1-0-35-30	20	27	48	60	135			
S1-25-35-30		33	49	85	Thick			
S1-50-35-30		45	62	106				
S1-75-35-30		63	83					
S1-100-35-30		69	94					
S1-125-35-30		91	111					
S1-150-35-30		102						
Plaster Sand								
S2-0-35-30	20	39	67	247				
S2-25-35-30		47	92	Thick				
S2-50-35-30		53	106					
S2-75-35-30		80	156					
S2-100-35-30		97	165					
S2-125-35-30		136	Thick					
S2-150-35-30		Thick						
Coarse Blasting Sand								
S3-0-35-30	19	38	86	250				
S3-25-35-30		40	104					
S3-50-35-30		50	120					
S3-75-35-30		59	Thick					
S3-100-35-30		93						
S3-125-35-30		118						
S3-150-35-30		Thick						
Medium Blasting Sand								
S4-0-35-30	20	36	76	180				
S4-25-35-30		42						
S4-50-35-30		52	121					
S4-75-35-30		69	139					
S4-100-35-30		93	155					
S4-125-35-30		112						
S4-150-35-30		147						
Fine Blasting Sand								
S5-0-35-30	19	39	67	240				
S5-25-35-30		42	72					
S5-50-35-30		66	139					
S5-75-35-30		90	Thick					
S5-100-35-30		133						
S5-125-35-30		330						
S5-150-35-30		Thick						

TABLE B1. CONCLUDED

Subgroup 4b (W / C + FA = 0.30)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
FAC 30-30 F	87	Thick						
S 25-30-30 F	150							
S 50-30-30 F	86	Thick						
S 75-30-30 F	71	210						

Subgroup 4c (W / C + FA = 0.40)

Mix identification code	Measurement time, T (T=x, min)							
	7	30	45	60	90	120	150	180
	Flow measurement, s							
FAC 40-30 F	14	15	16	18	22	31	47	68
S 50-40-30 F	13	15	15	16	19	23	27	32
S 100-40-30 F	19	53	60	84	98	113		
S 150-40-30 F	20		39	41	51	61	71	81
S 200-40-30 F	34	49		75	88	118		

APPENDIX C

STRESS/STRAIN AND LOAD/DEFLECTION CURVES

This appendix presents all the stress-versus-strain and load-versus-deflection curves of SIFCON for each of the study groups (Figs. C1 through C96). The figures are arranged according to their respective study groups. Compression, flexure, shear, and tension curves are identified in the figure titles. Nearly all mixes were tested in both compression and flexure. Therefore a set of compression and flexure curves for each of these mixes is included. Each mix tested in compression is, in general, represented by four individual superimposed curves recording the results of each individual test. The heavy, dark superimposed curve records the average of the four curves. The flexure curves are similar except that there are generally five individual superimposed curves along with the average curve. A few specimens were tested in shear (Figs. C87-90) and tension (Figs. C92-C96). These shear and tension tests are plotted similarly to compression and flexure. All curves of every type of test represent 30-day test results. Each figure also contains all ultimate strength values for the respective individual tests. Ultimate 30-day slurry strengths are included on the respective SIFCON compression figures.

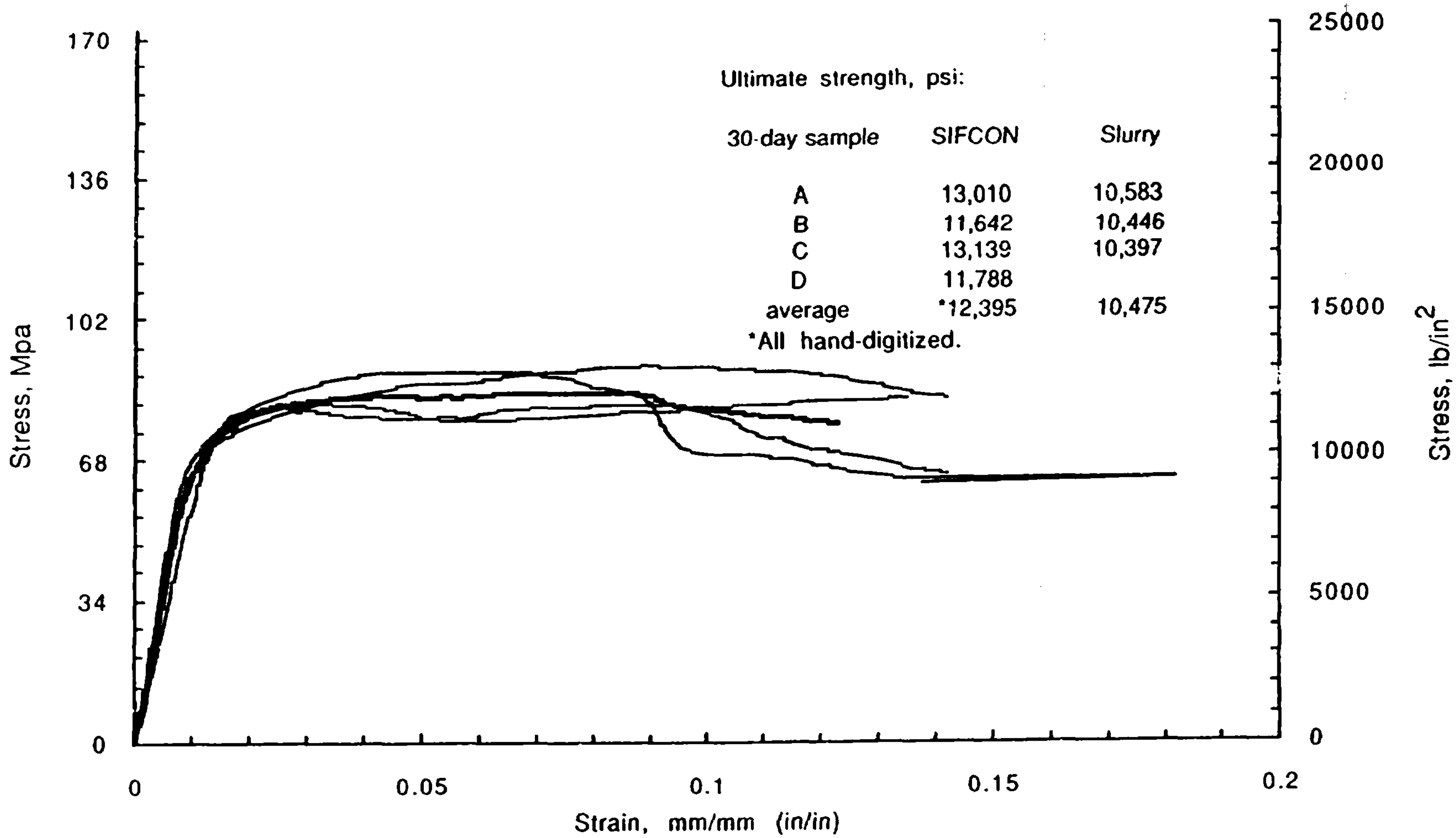


Figure C1. CW 28-30 compression.

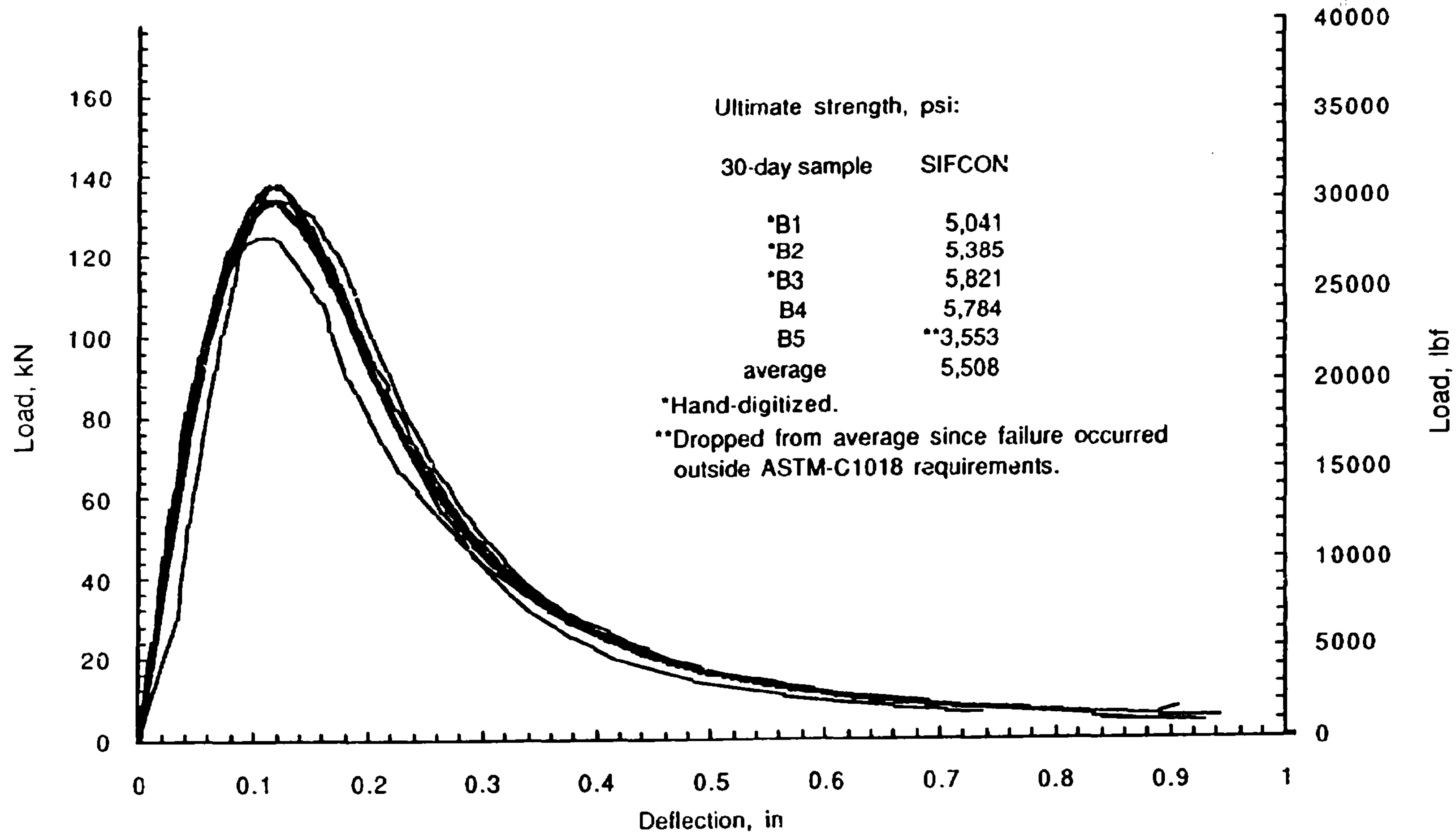


Figure C2. CW 28-30 flexure.

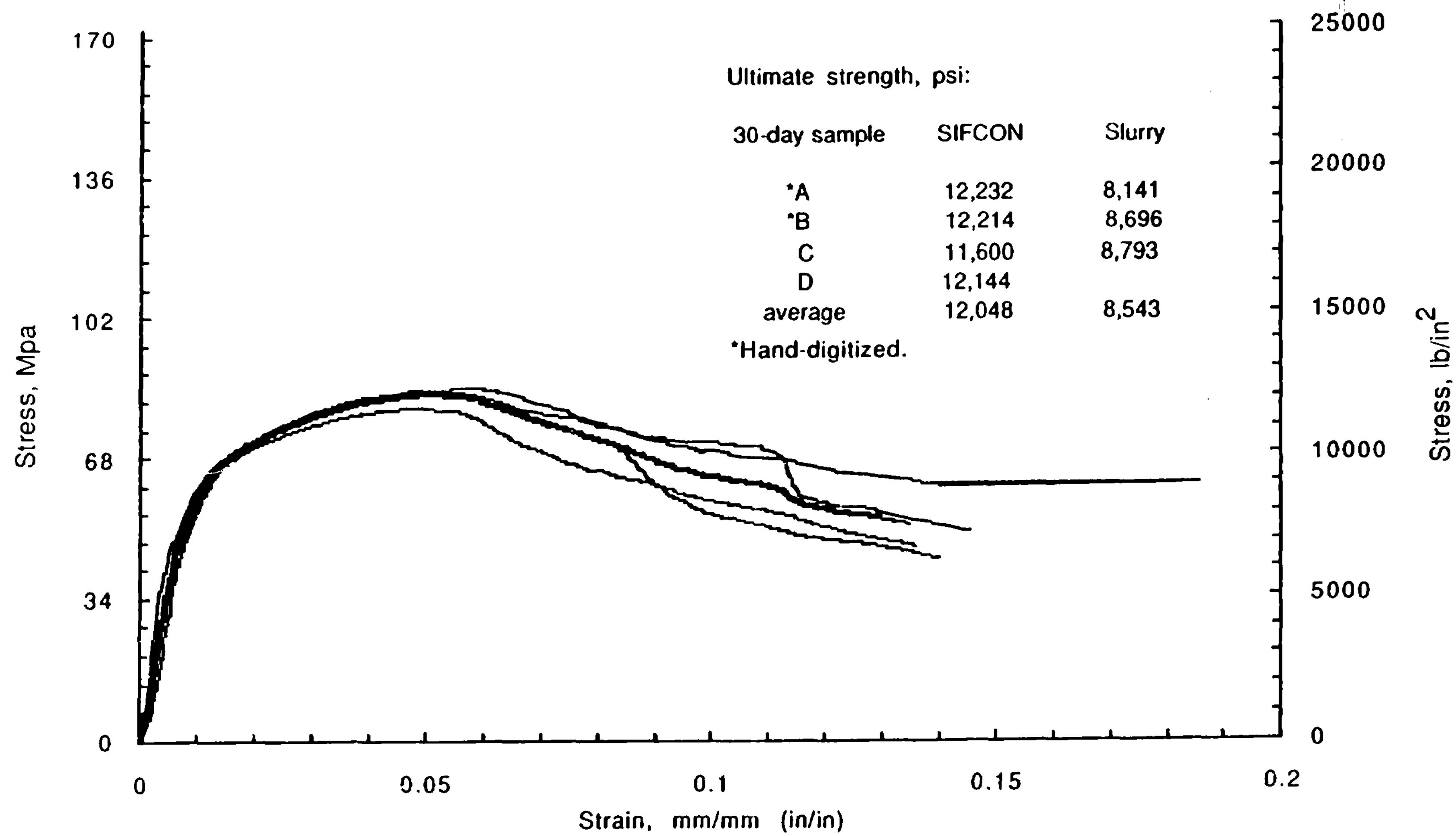


Figure C3. CW 33-30 compression.

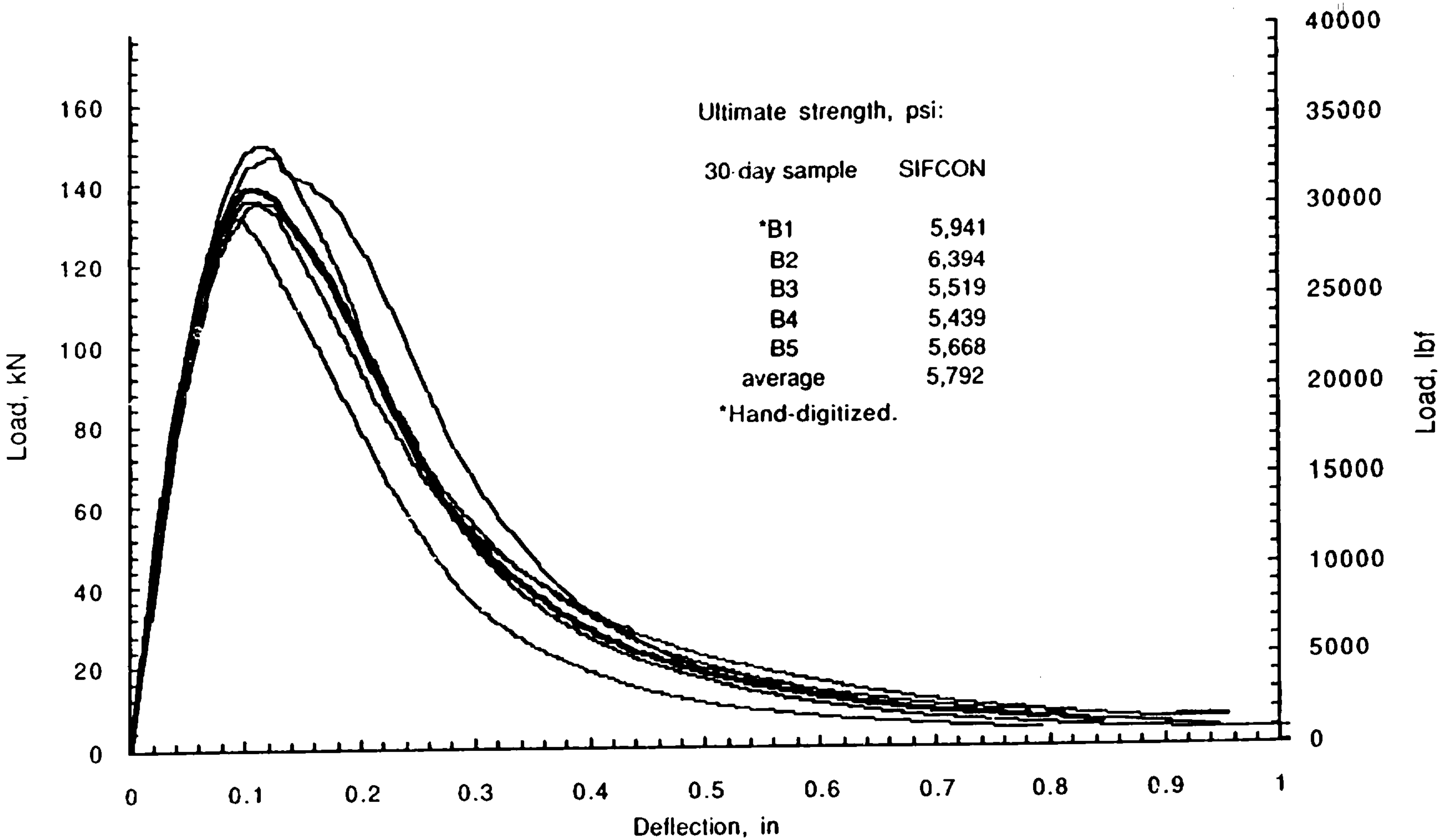


Figure C4. CW 33-30 flexure.

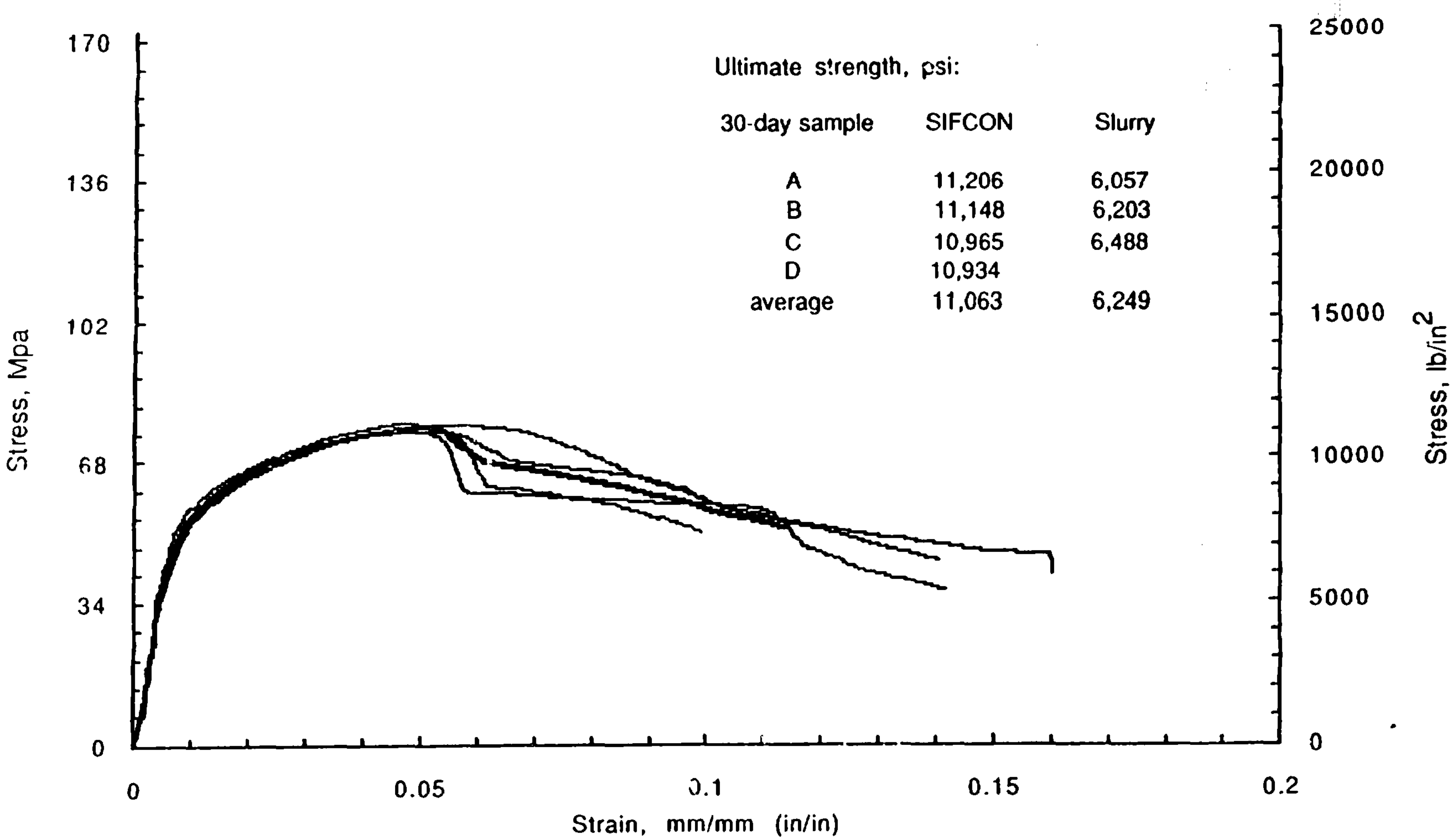


Figure C5. CW 38-30 compression.

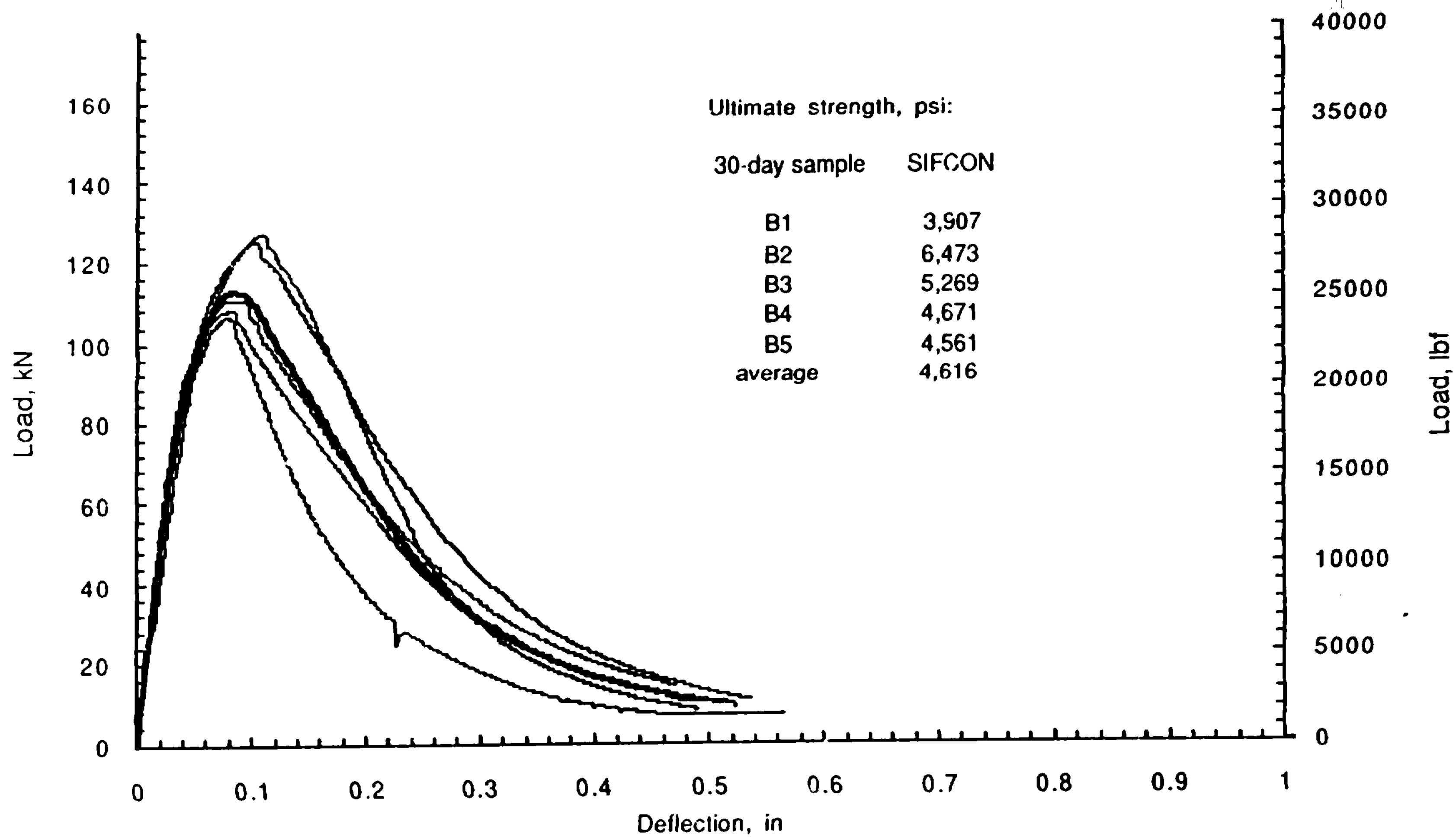


Figure C6. CW 38-30 flexure.

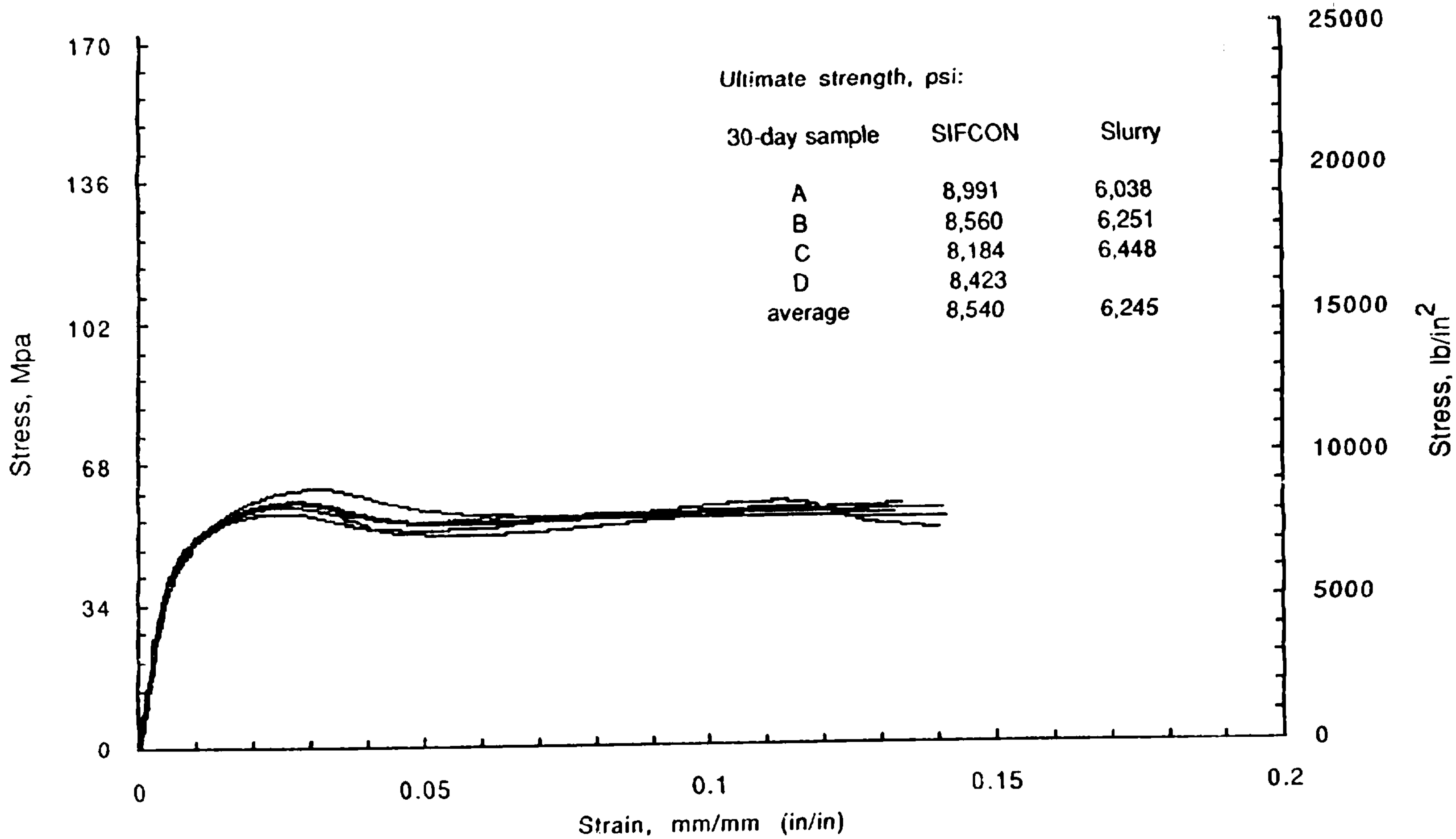


Figure C7. CW 43-30 compression.

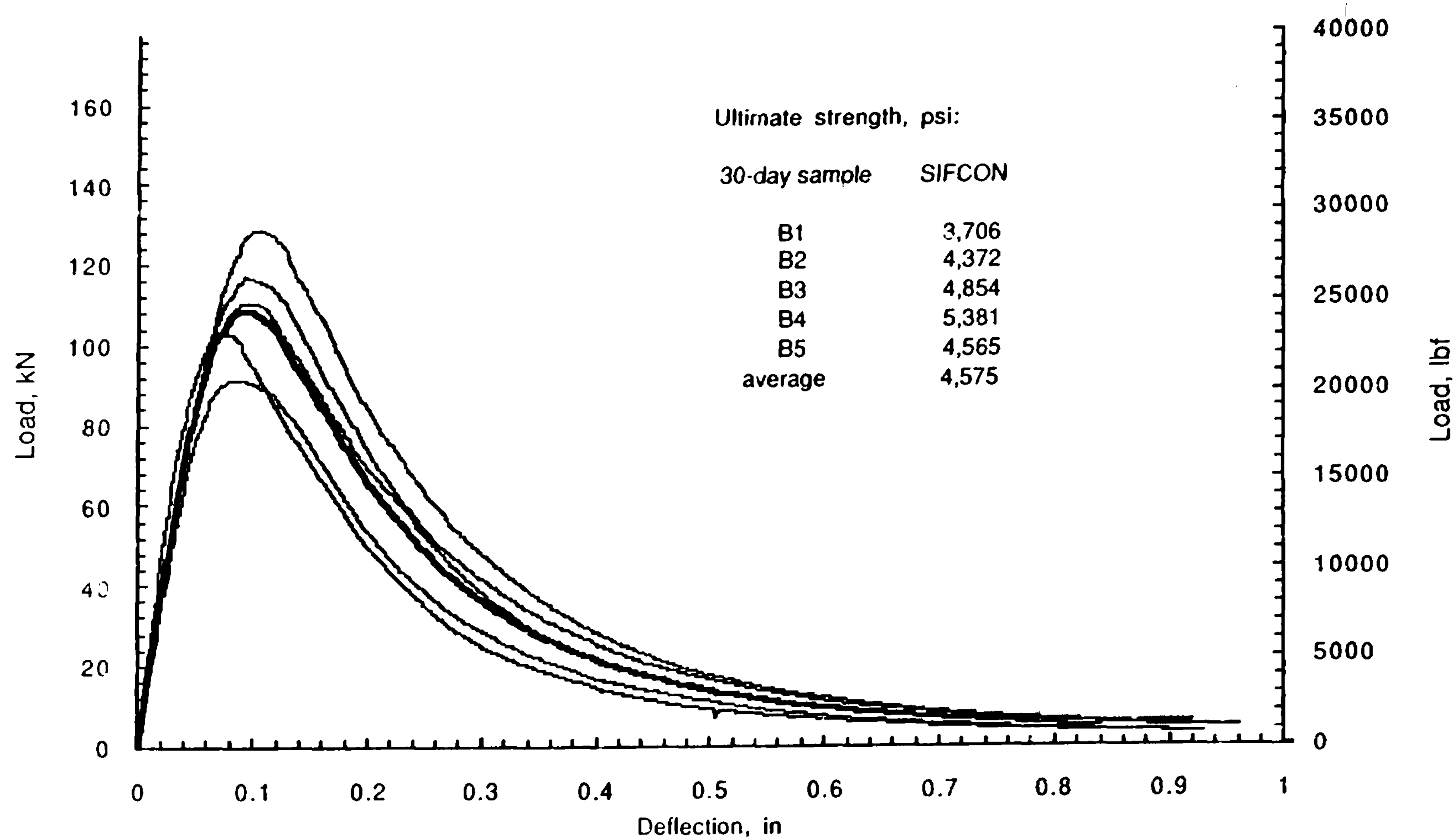


Figure C8. CW 43-30 flexure.

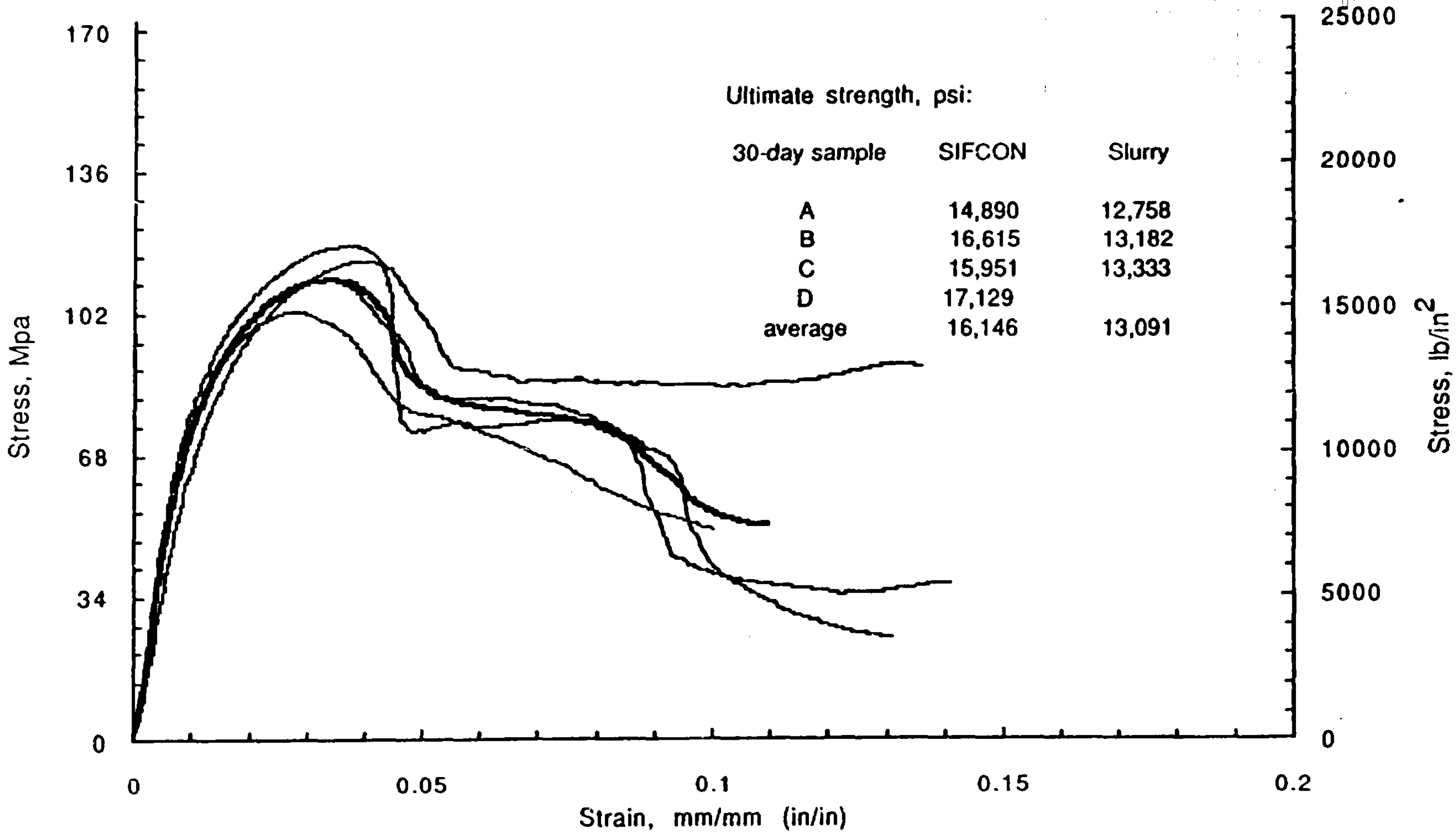


Figure C9. FAC 30-0 F compression.

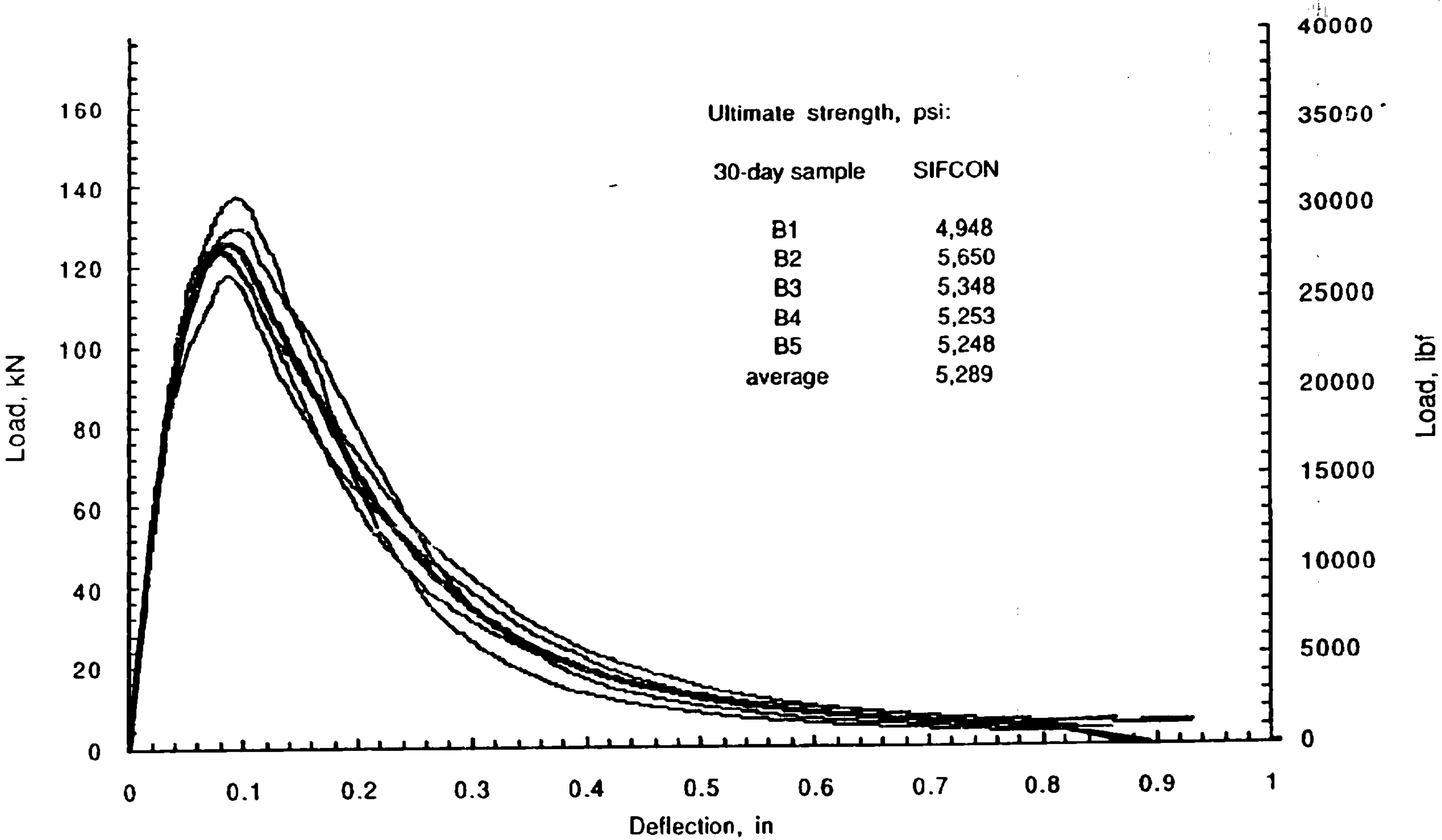


Figure C10. FAC 30-0 F flexure.

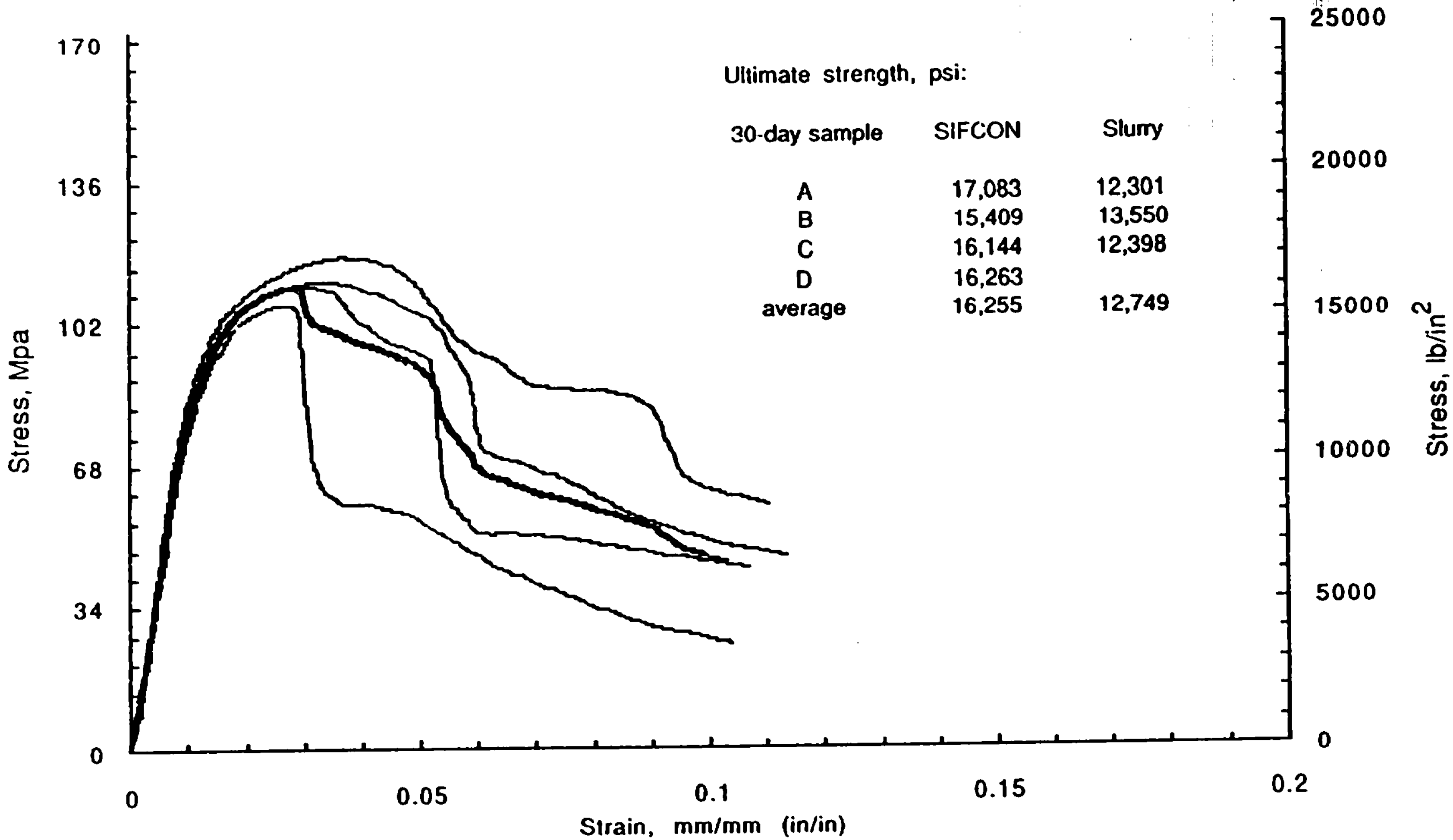


Figure C11. FAC 30-10 F compression.

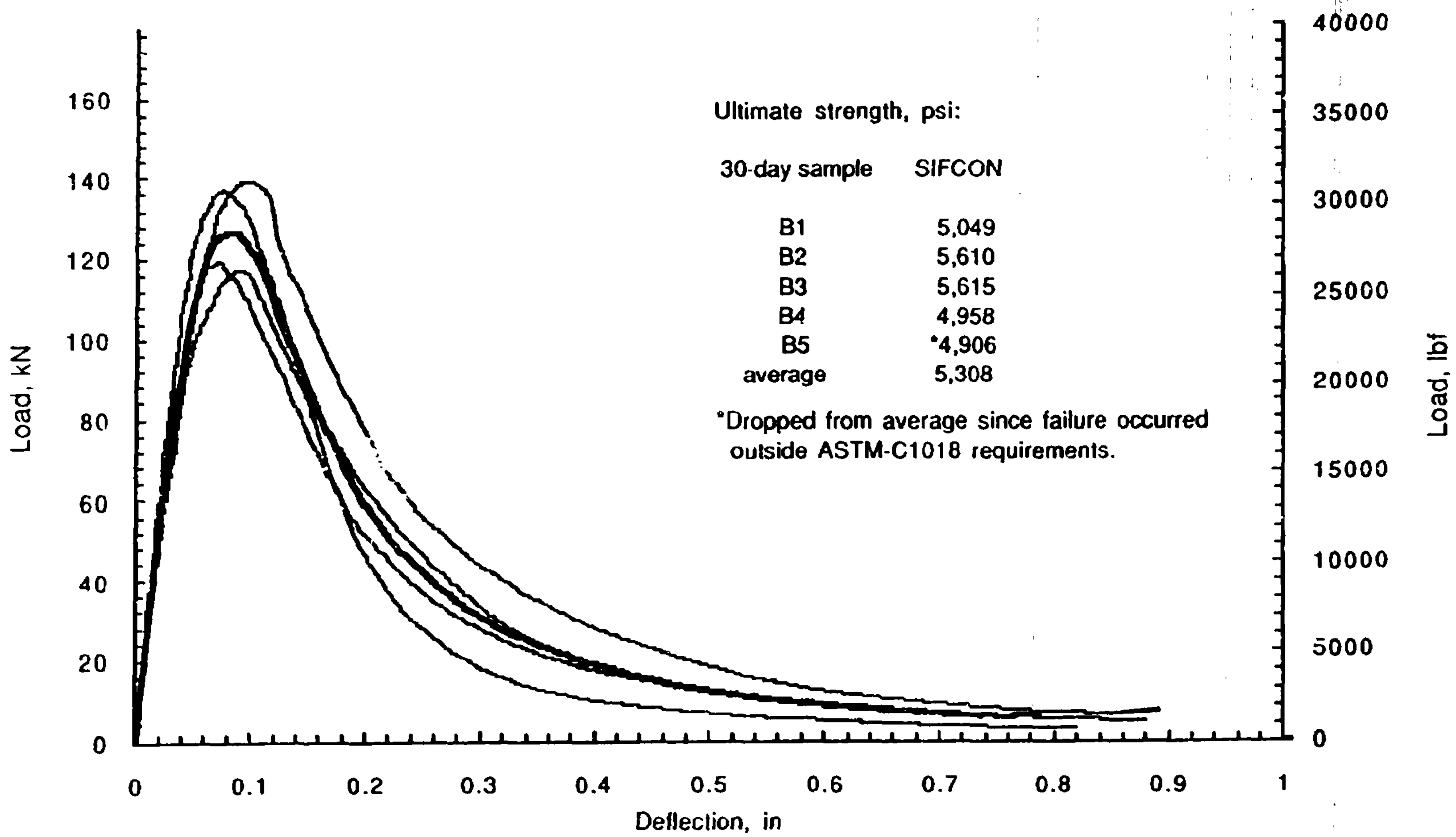


Figure C12. FAC 30-10 F flexure.

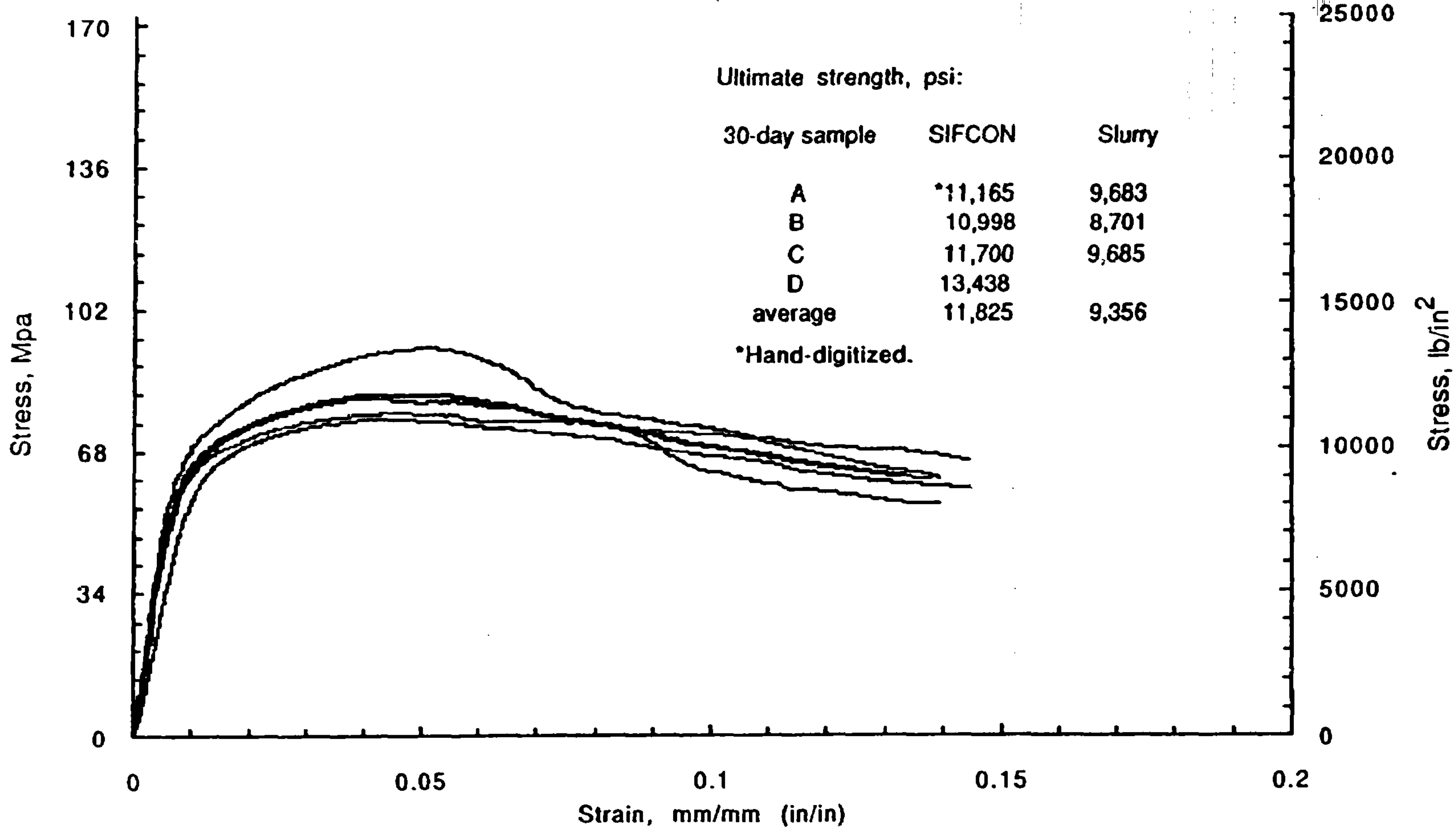


Figure C13. FAC 30-30 F compression.

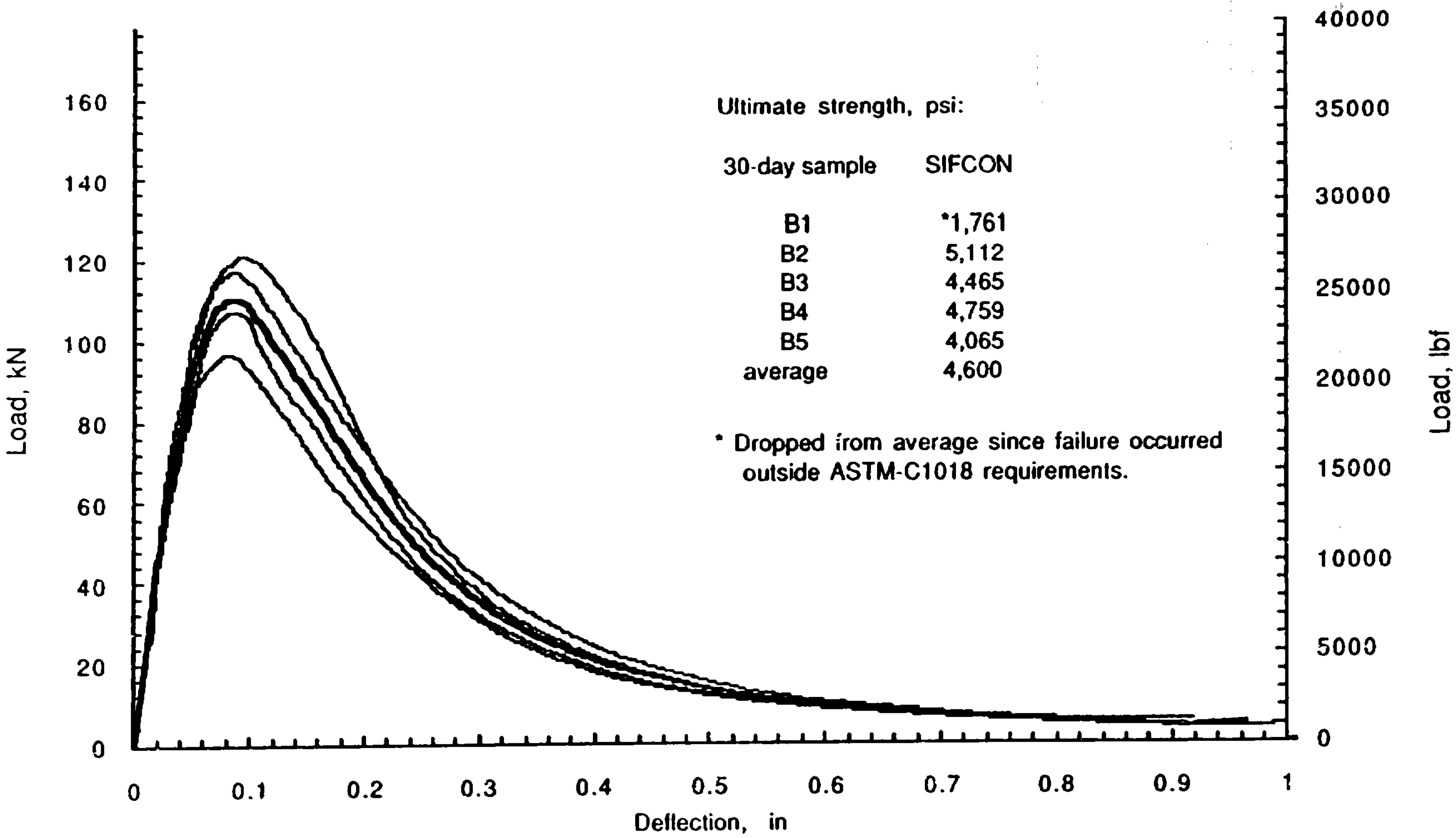


Figure C14. FAC 30-30 F flexure.

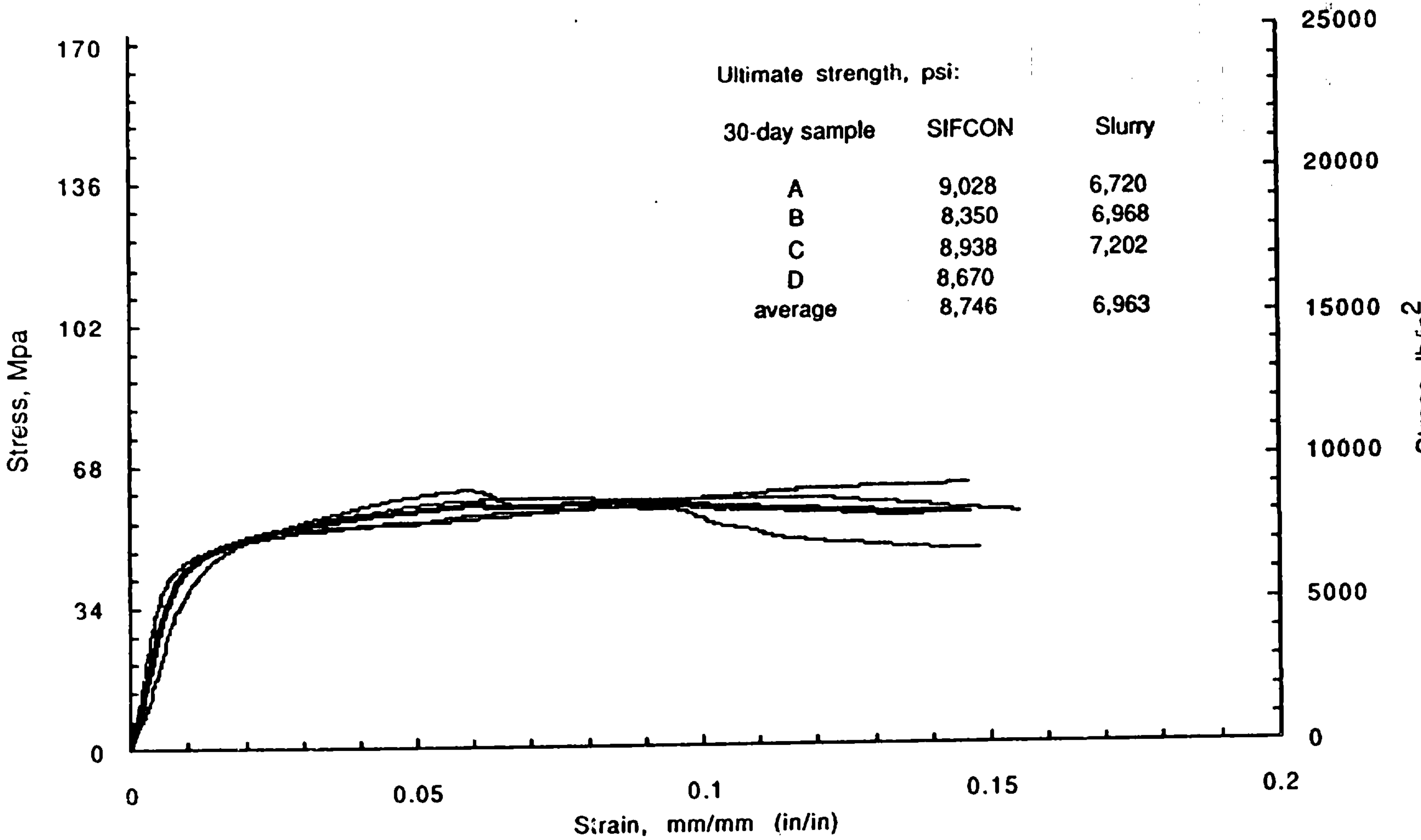


Figure C15. FAC 30-50 F compression.

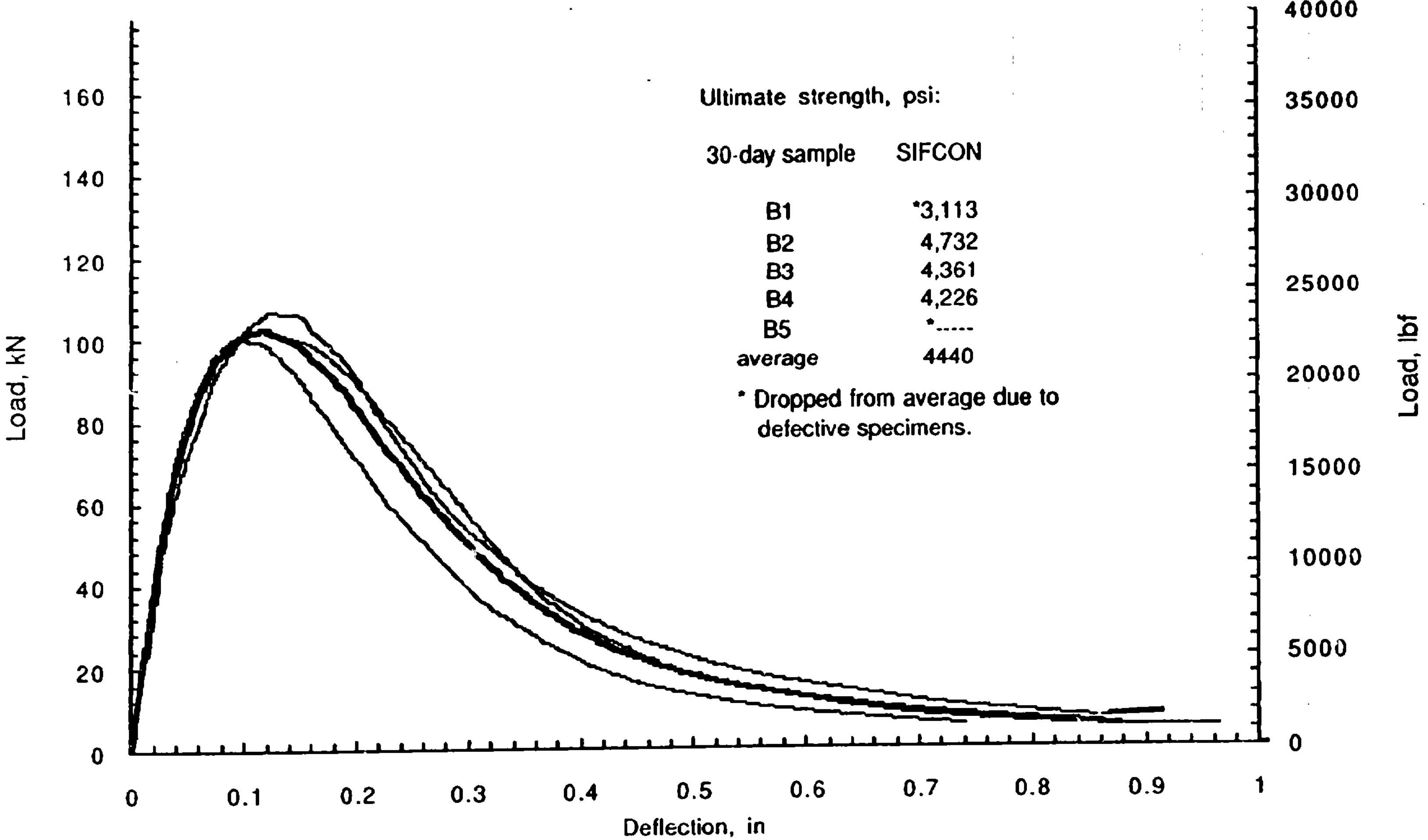


Figure C16. FAC 30-50 F flexure.

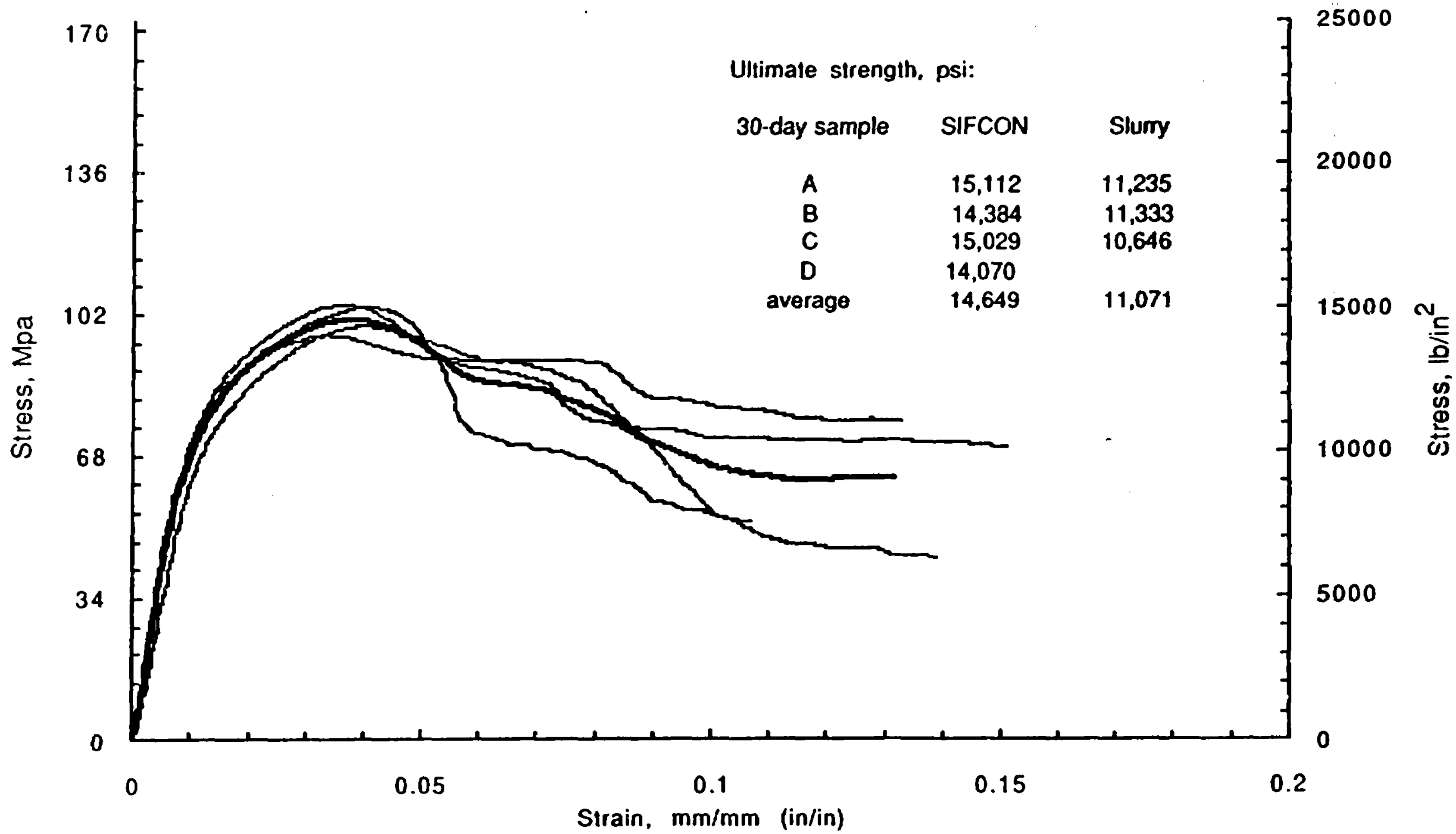


Figure C17. FAC 40-0 F compression.

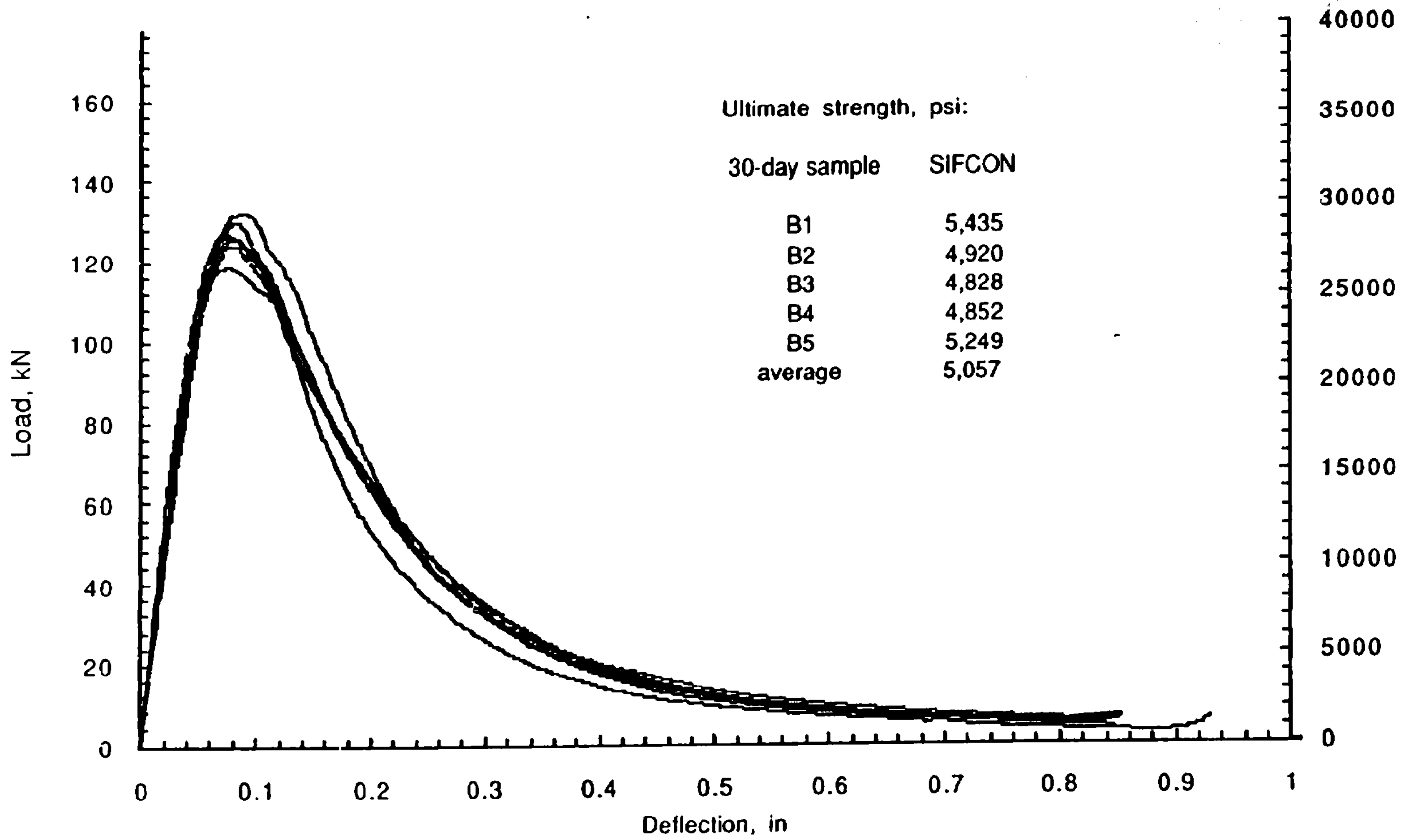


Figure C18. FAC 40-0 F flexure.

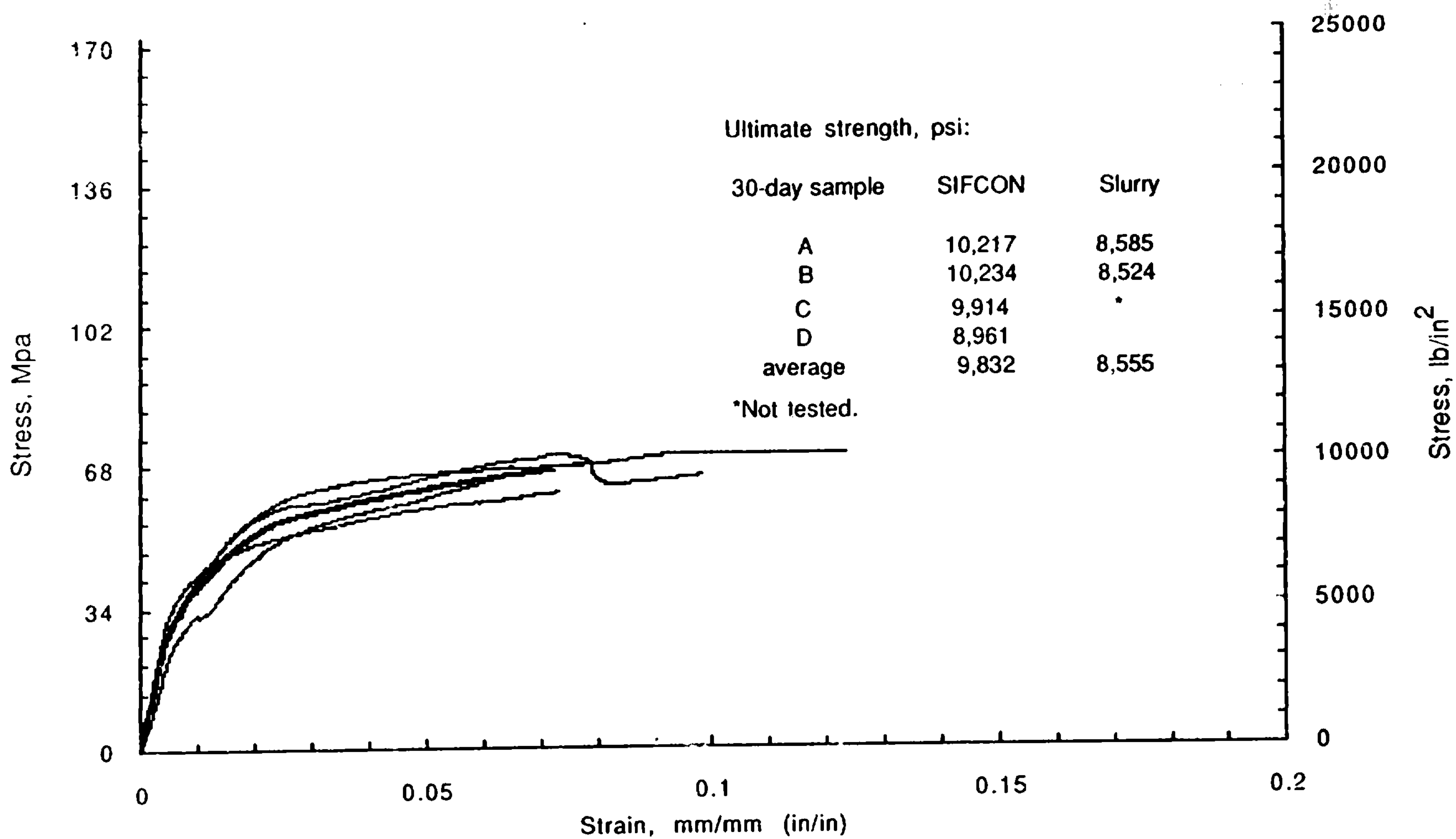


Figure C19. FAC 40-10 F compression.

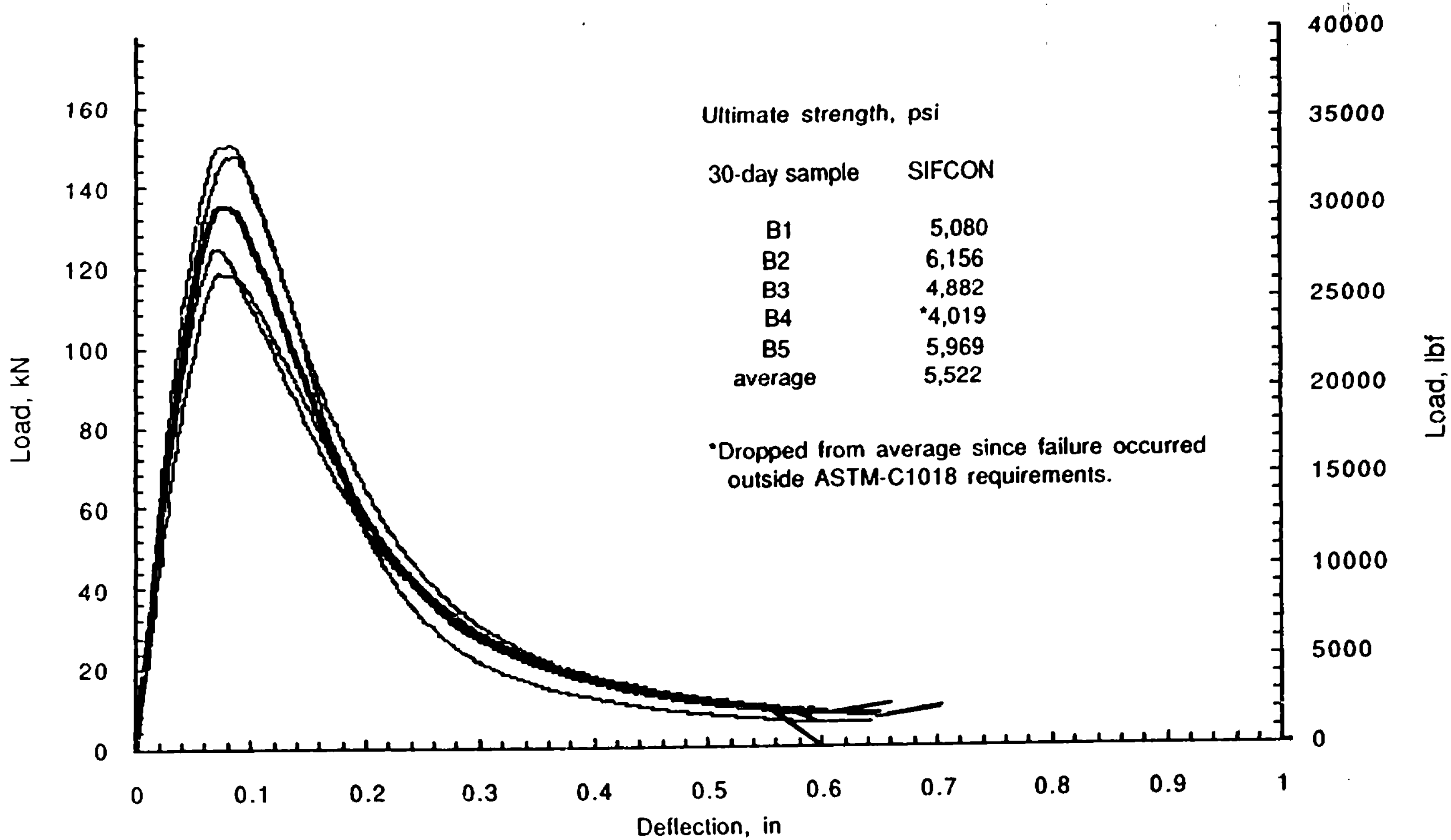


Figure C20. FAC 40-10 F flexure.

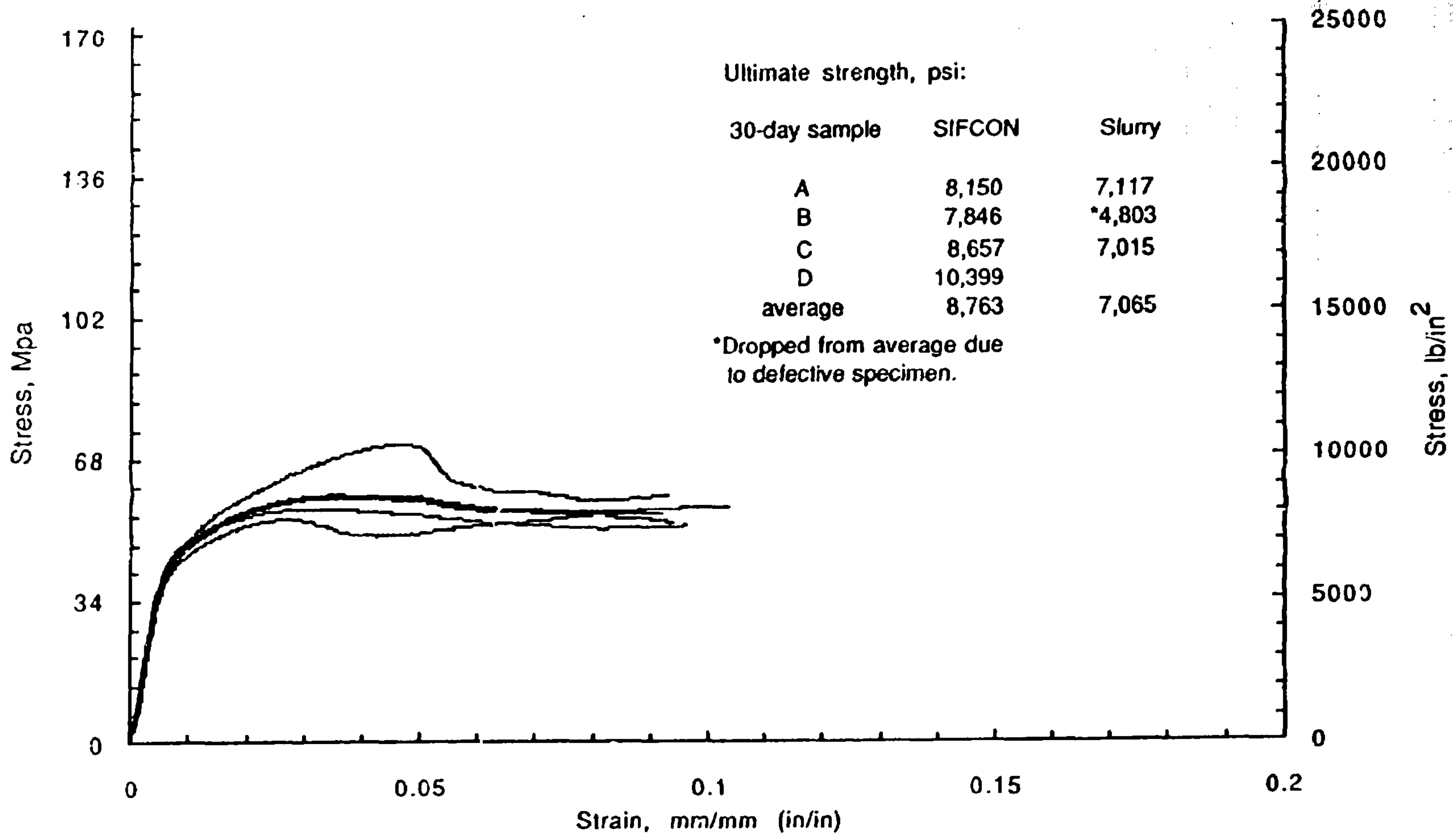


Figure C21. FAC 40-30 F compression.

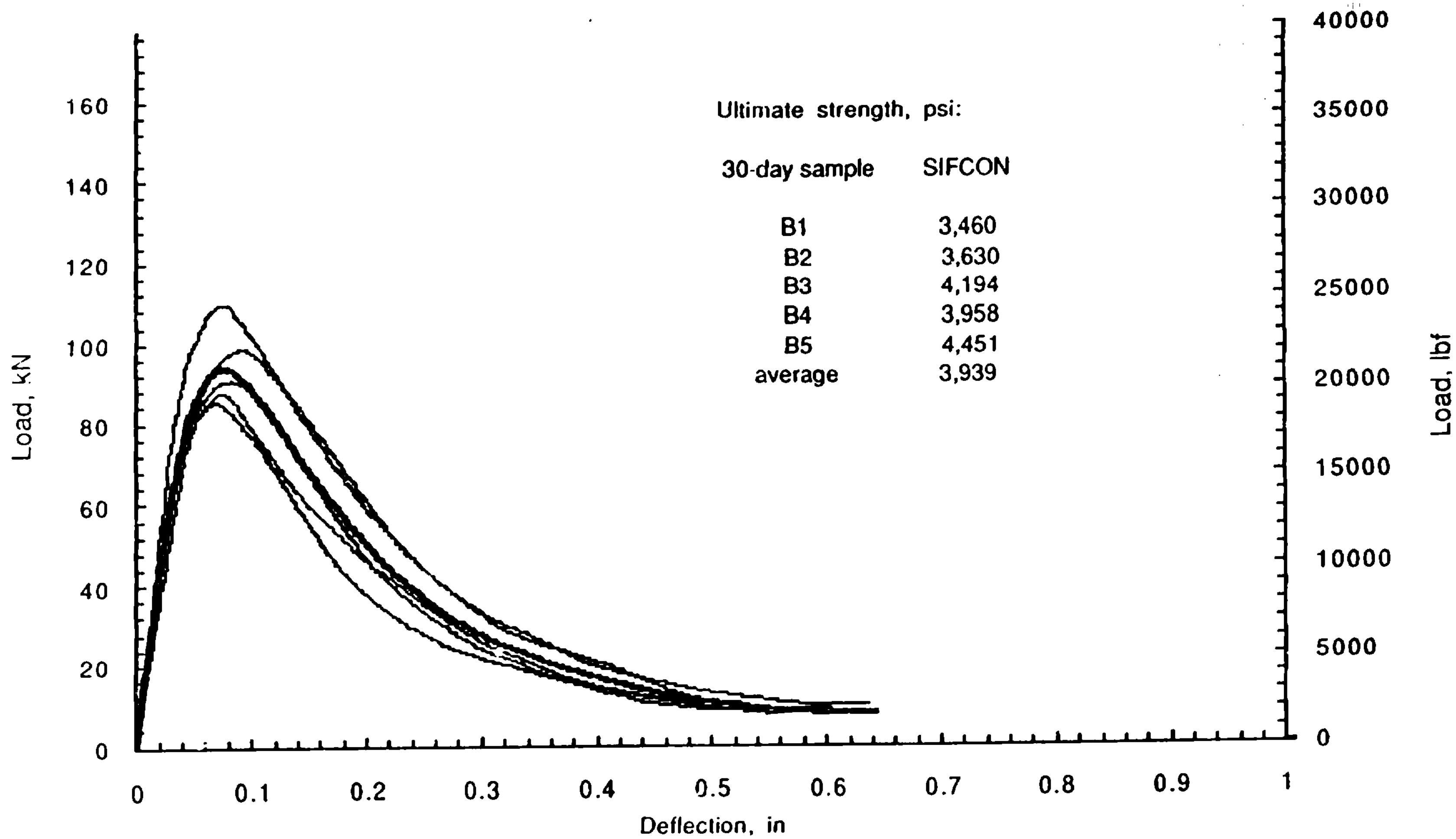


Figure C22. FAC 40-30 F flexure.

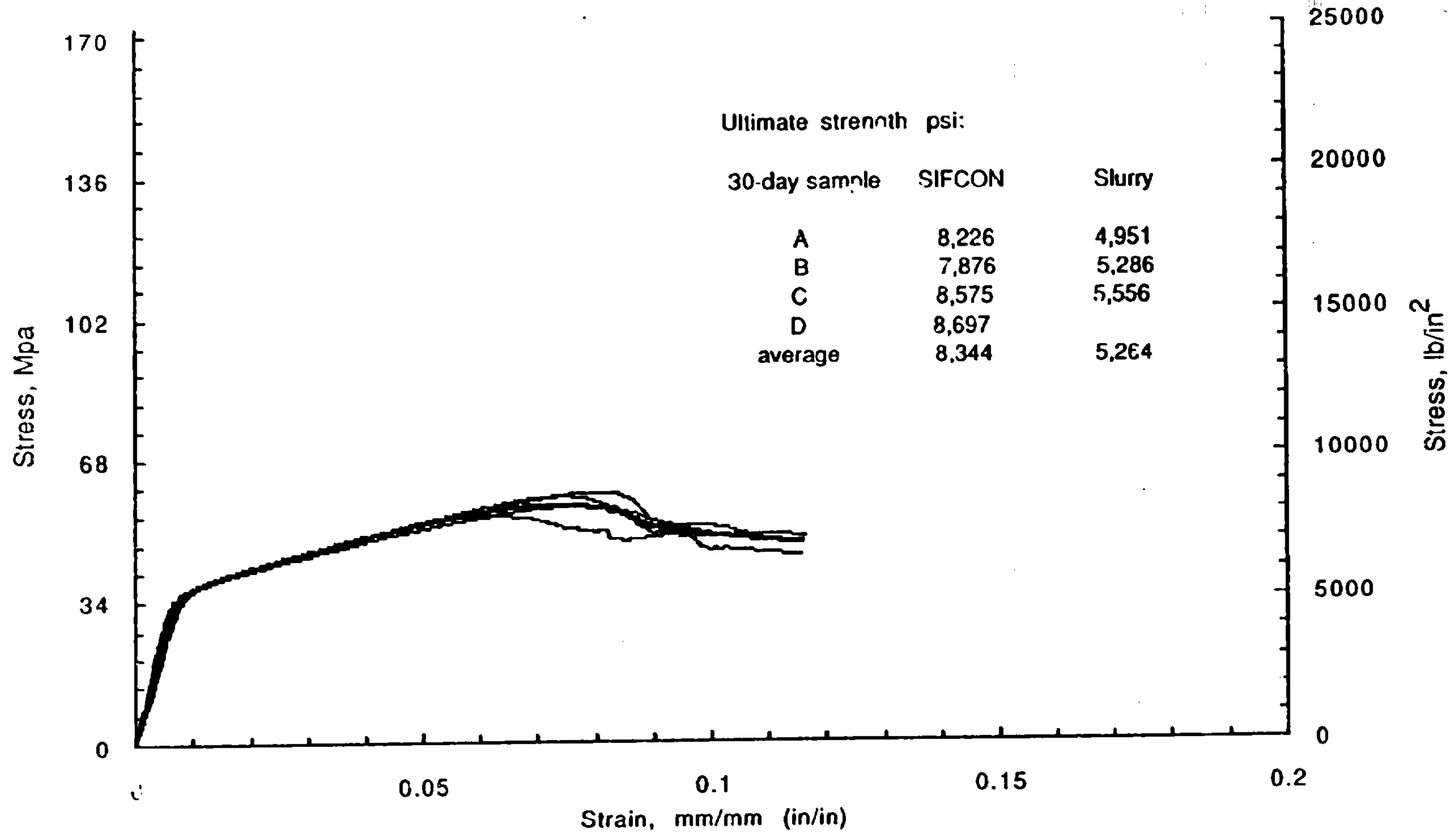


Figure C23. FAC 40-50 F compression.

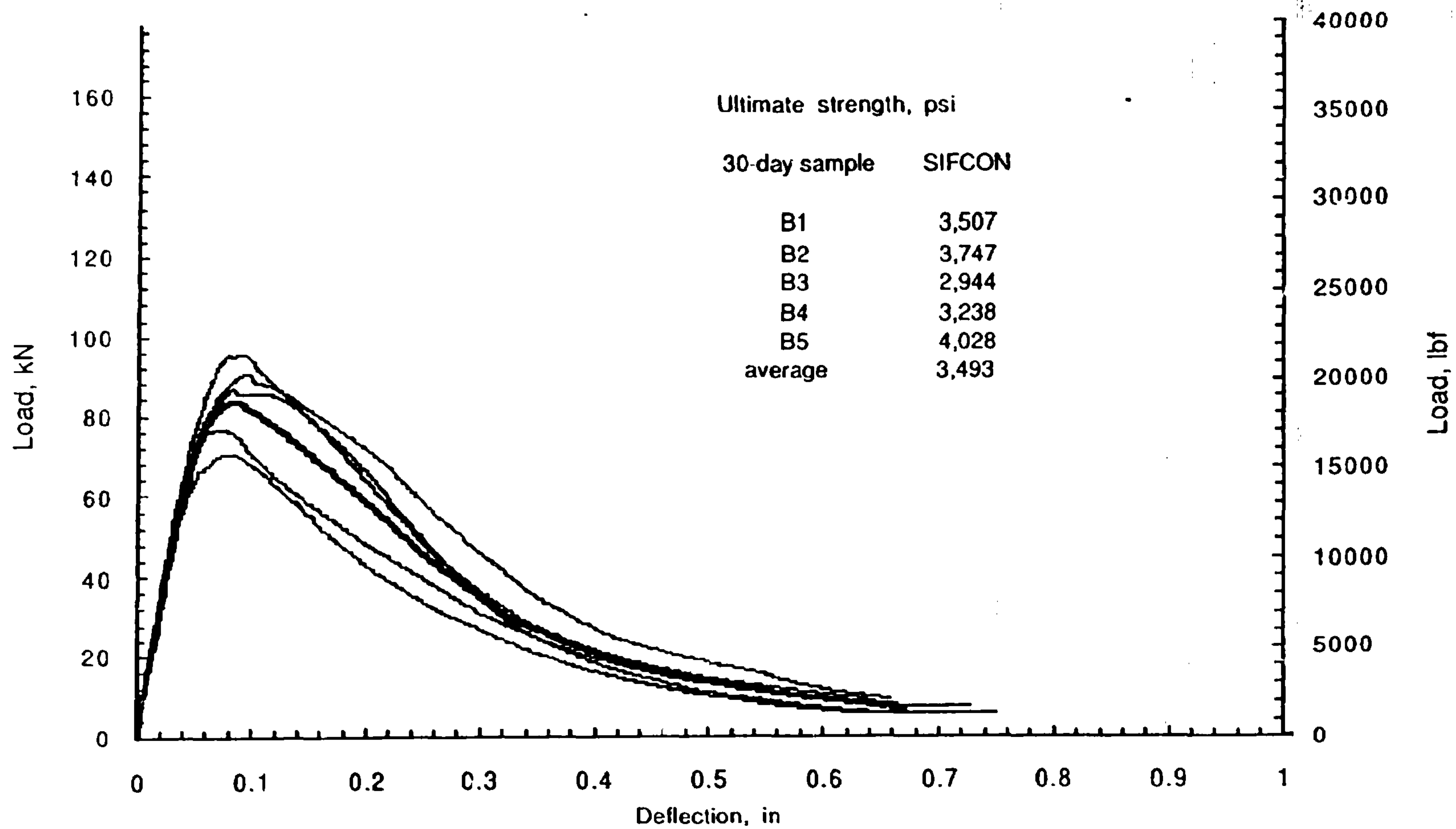


Figure C24. FAC 40-50 F flexure.

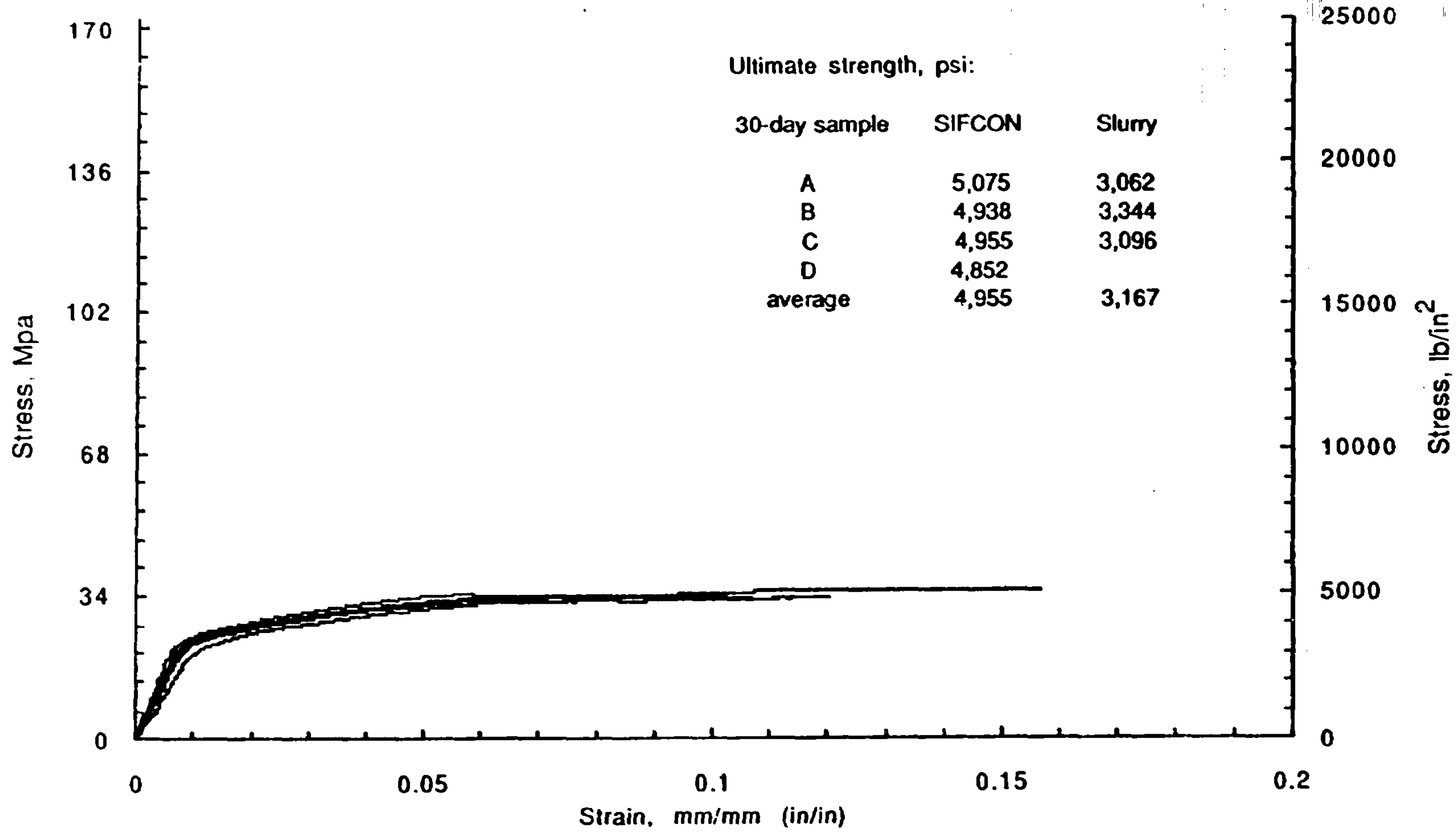


Figure C25. FAC 40-80 F compression.

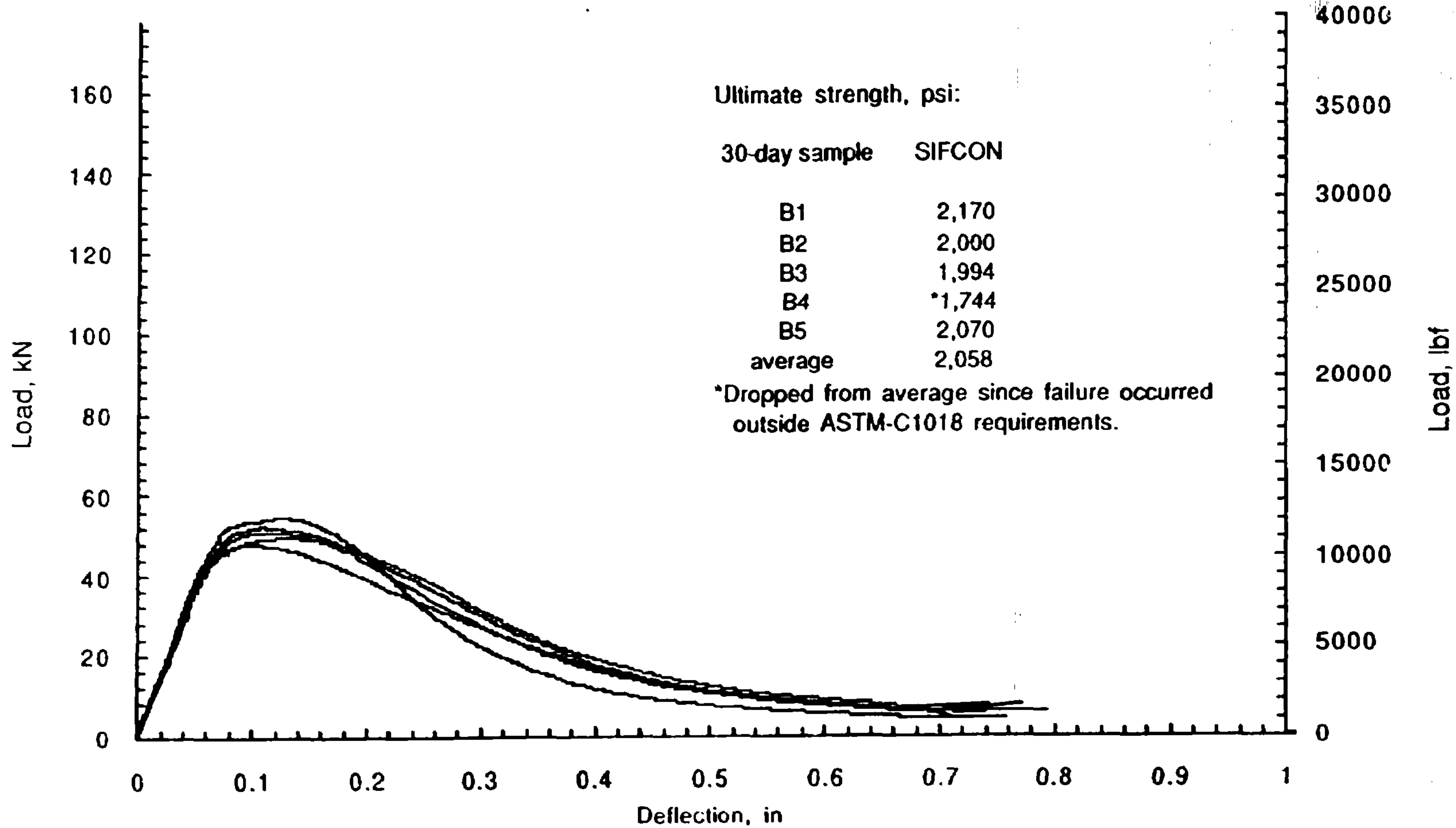


Figure C26. FAC 40-80 F flexure.

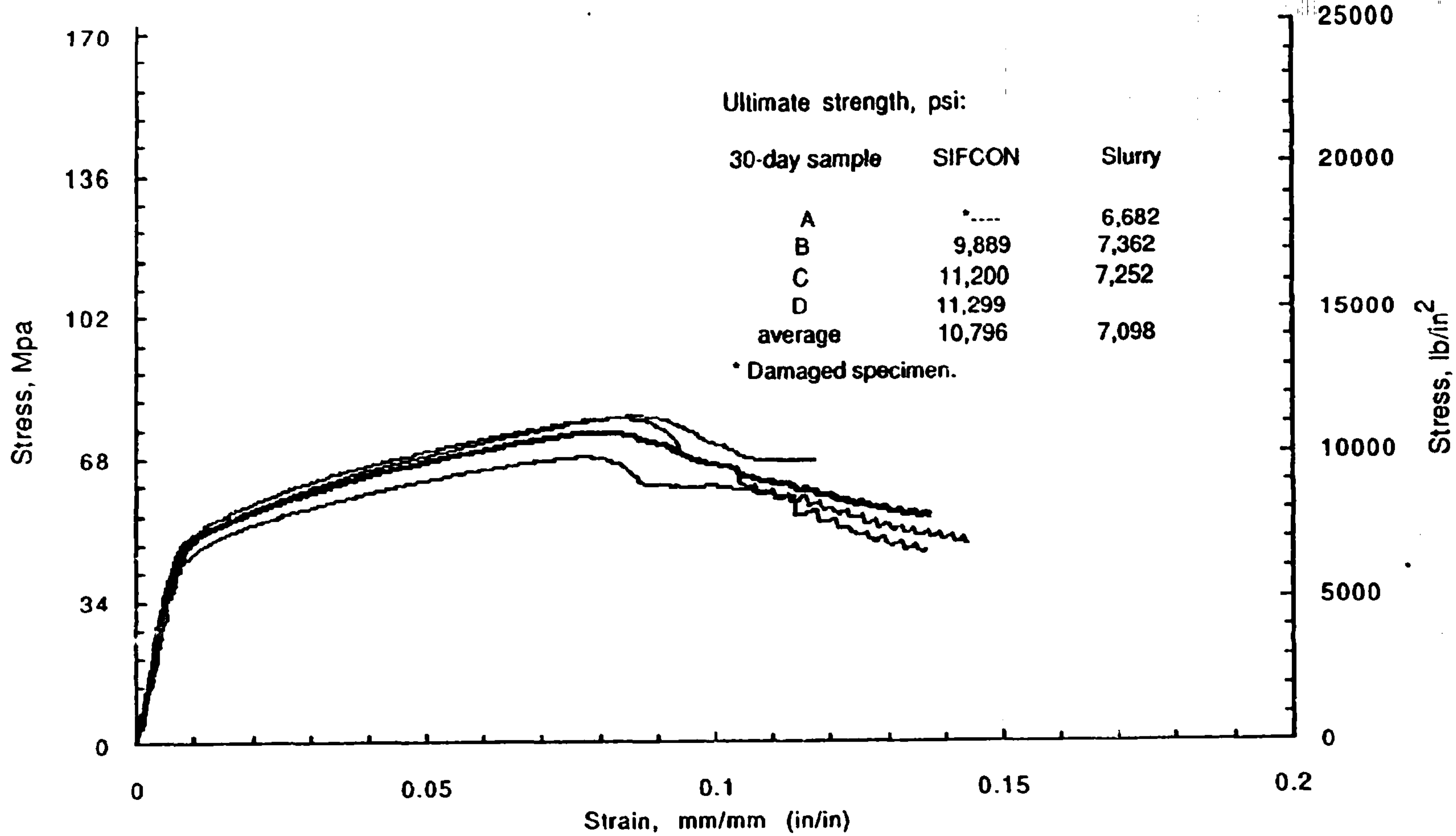


Figure C27. Z 3/4-35-30 F compression.

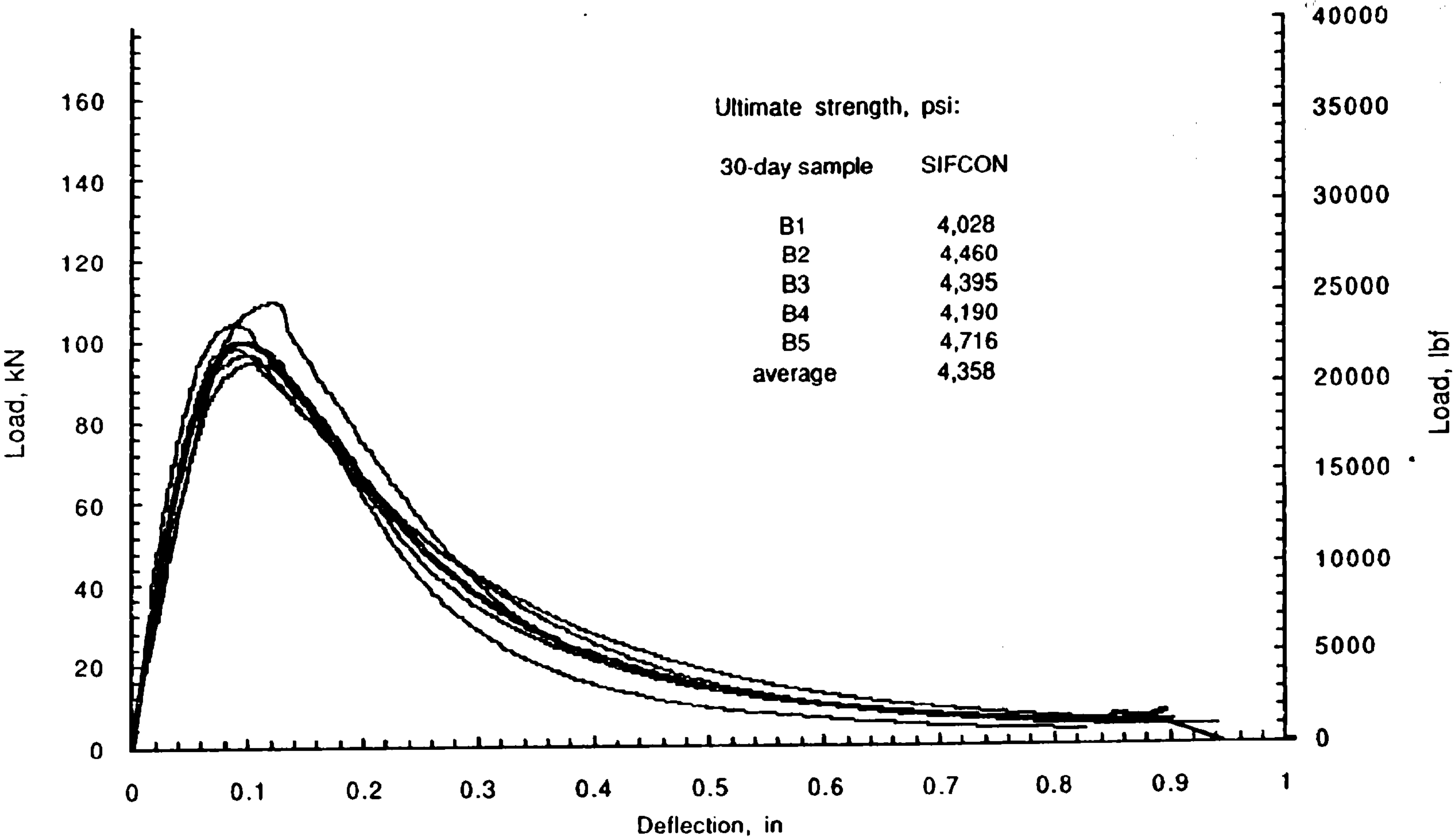


Figure C28. Z 3/4-35-30 F flexure.

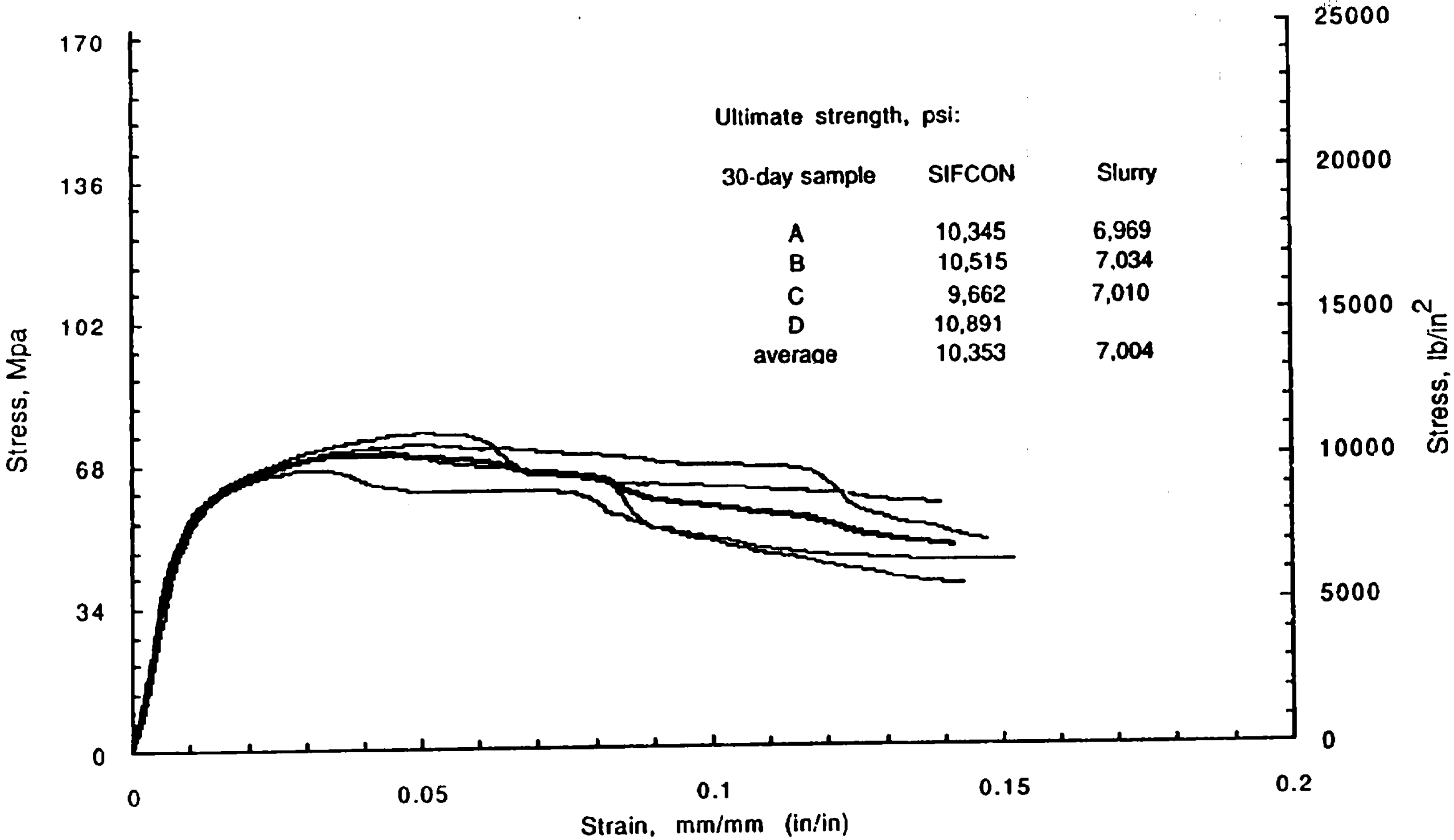


Figure C29. Z 3/5-35-30 F compression.

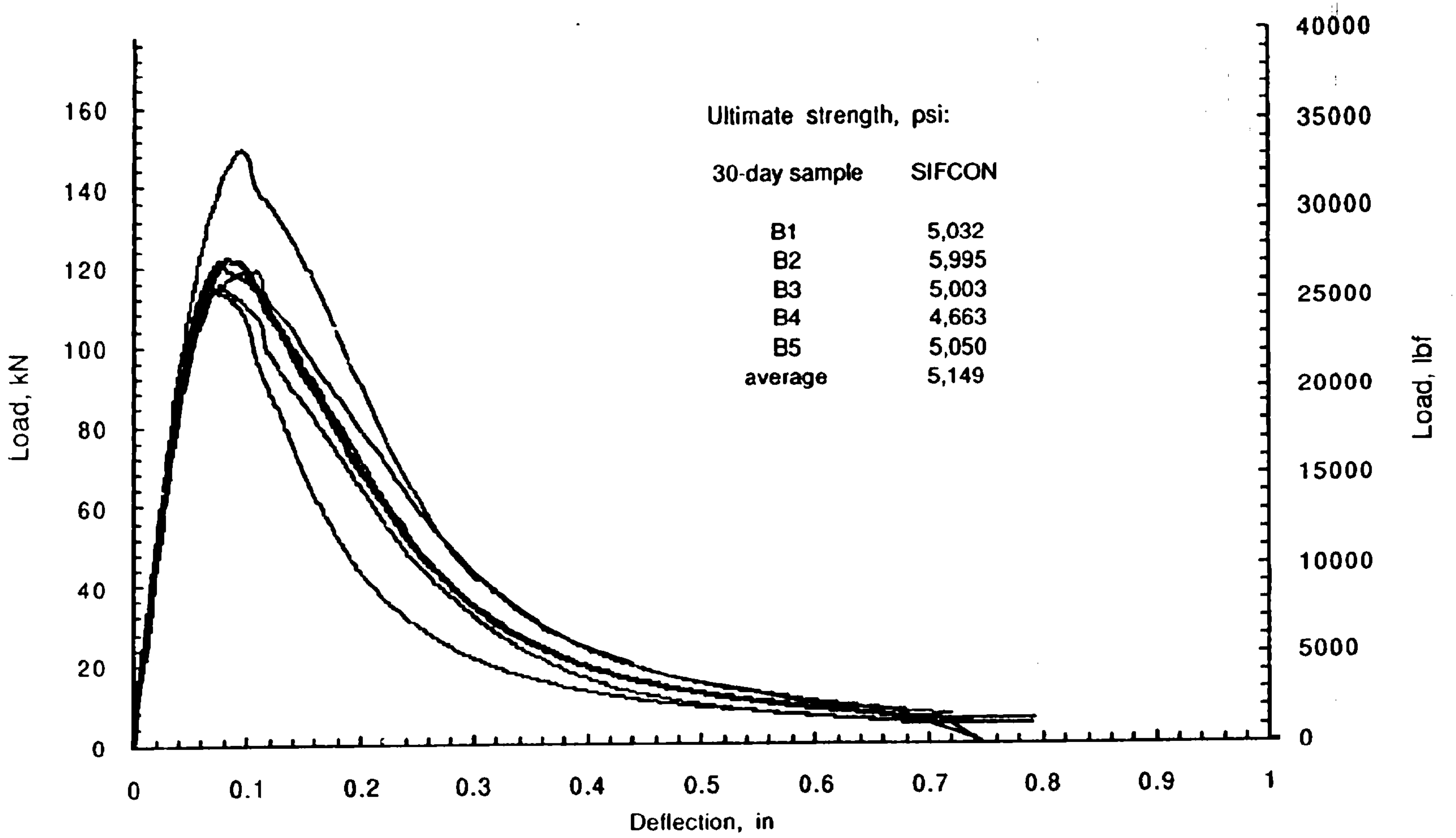


Figure C30. Z 3/5-35-30 F flexure.

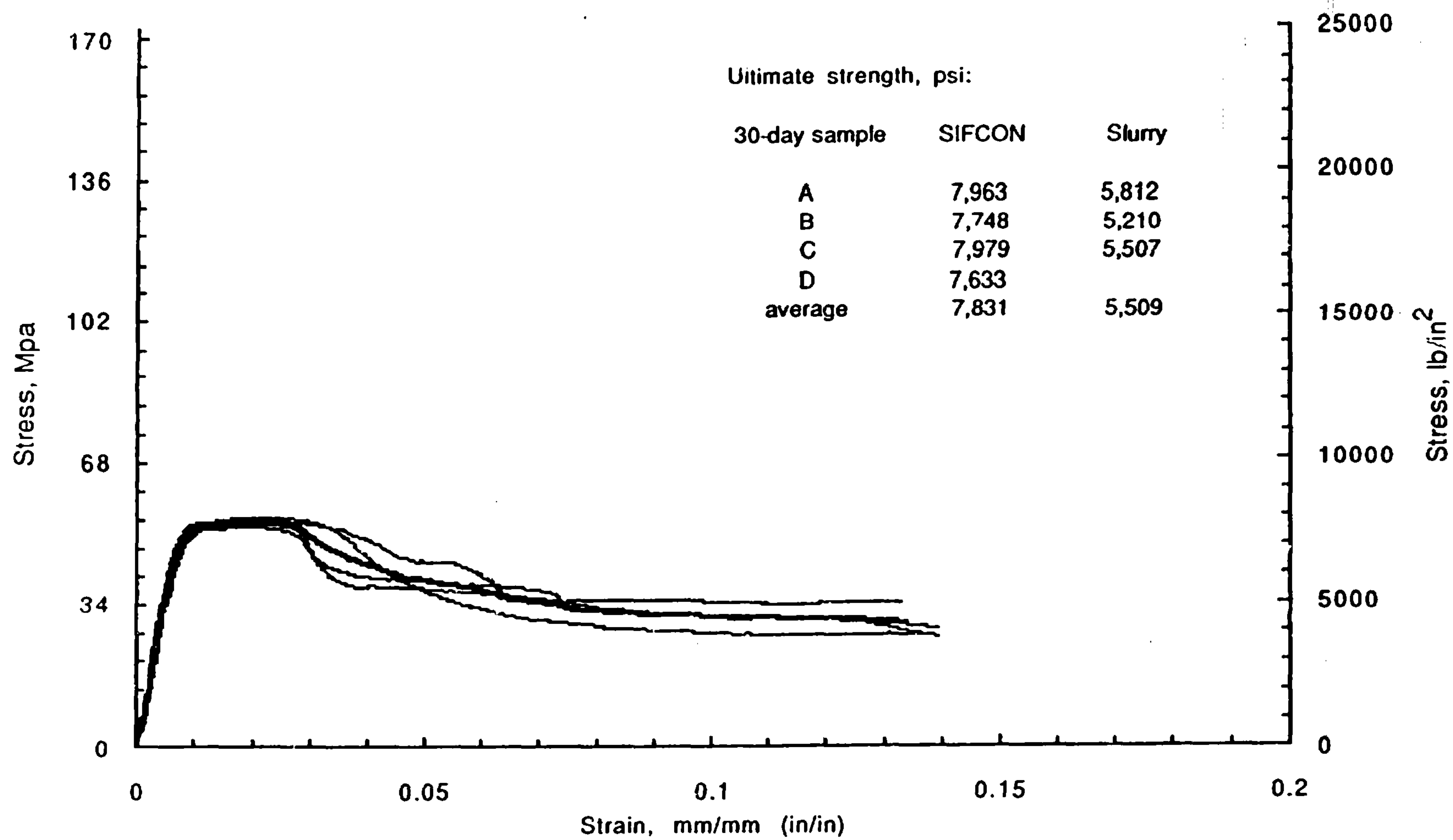


Figure C31. Z 5/5-35-30 F compression.

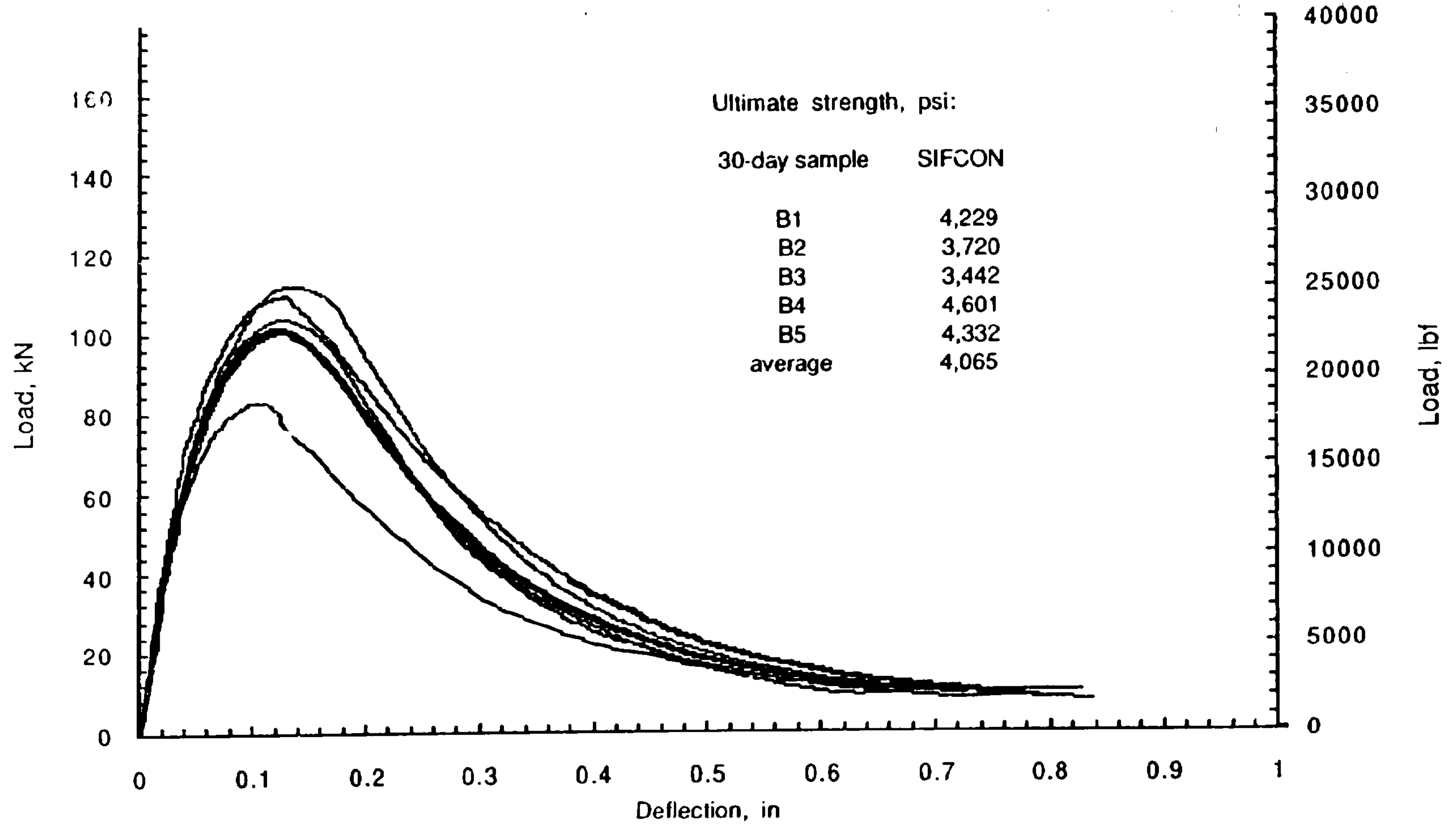


Figure C32. Z 5/5-35-30 F flexure.

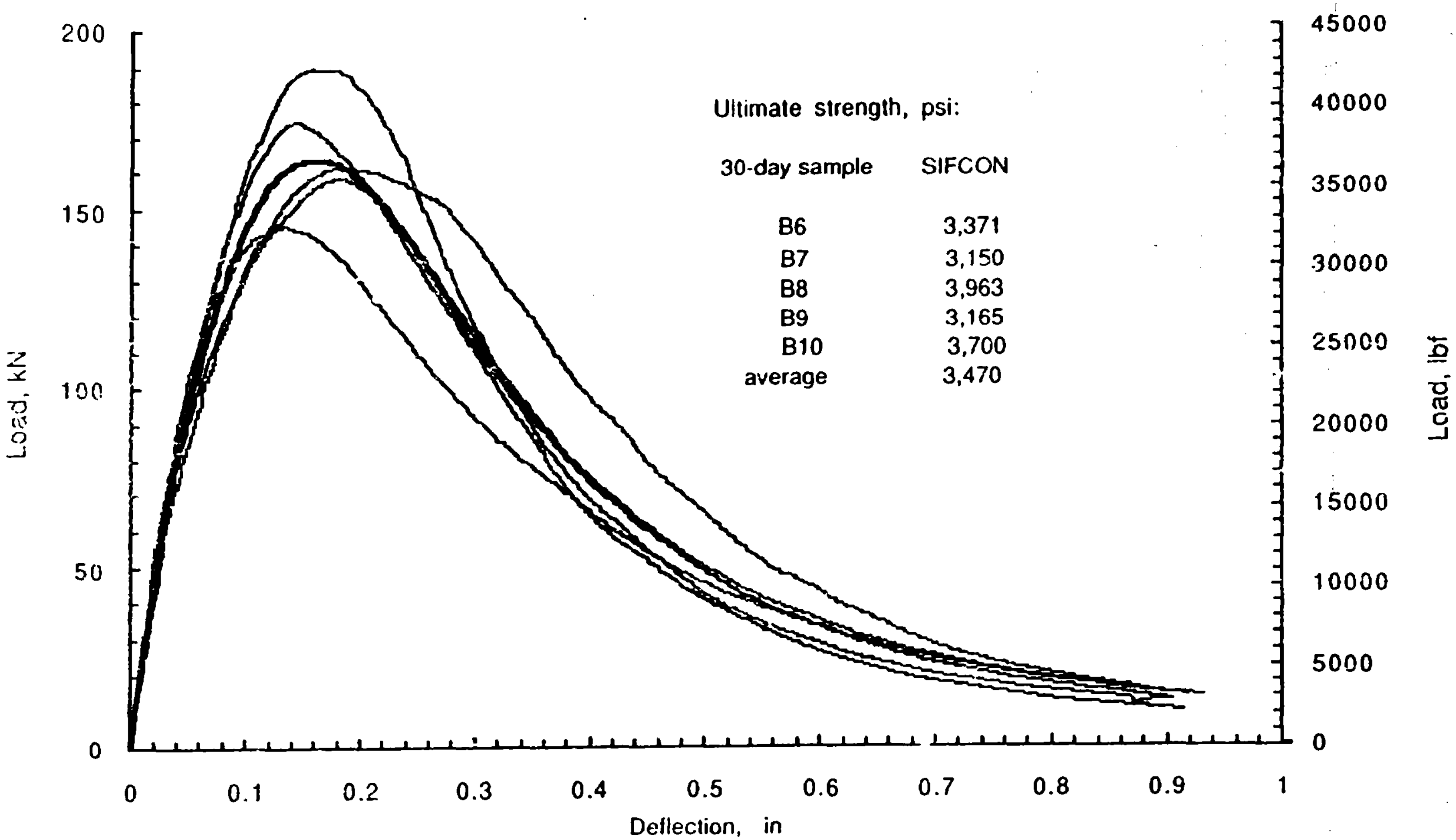


Figure C33. Z 5/5-35-30 F (large) flexure.

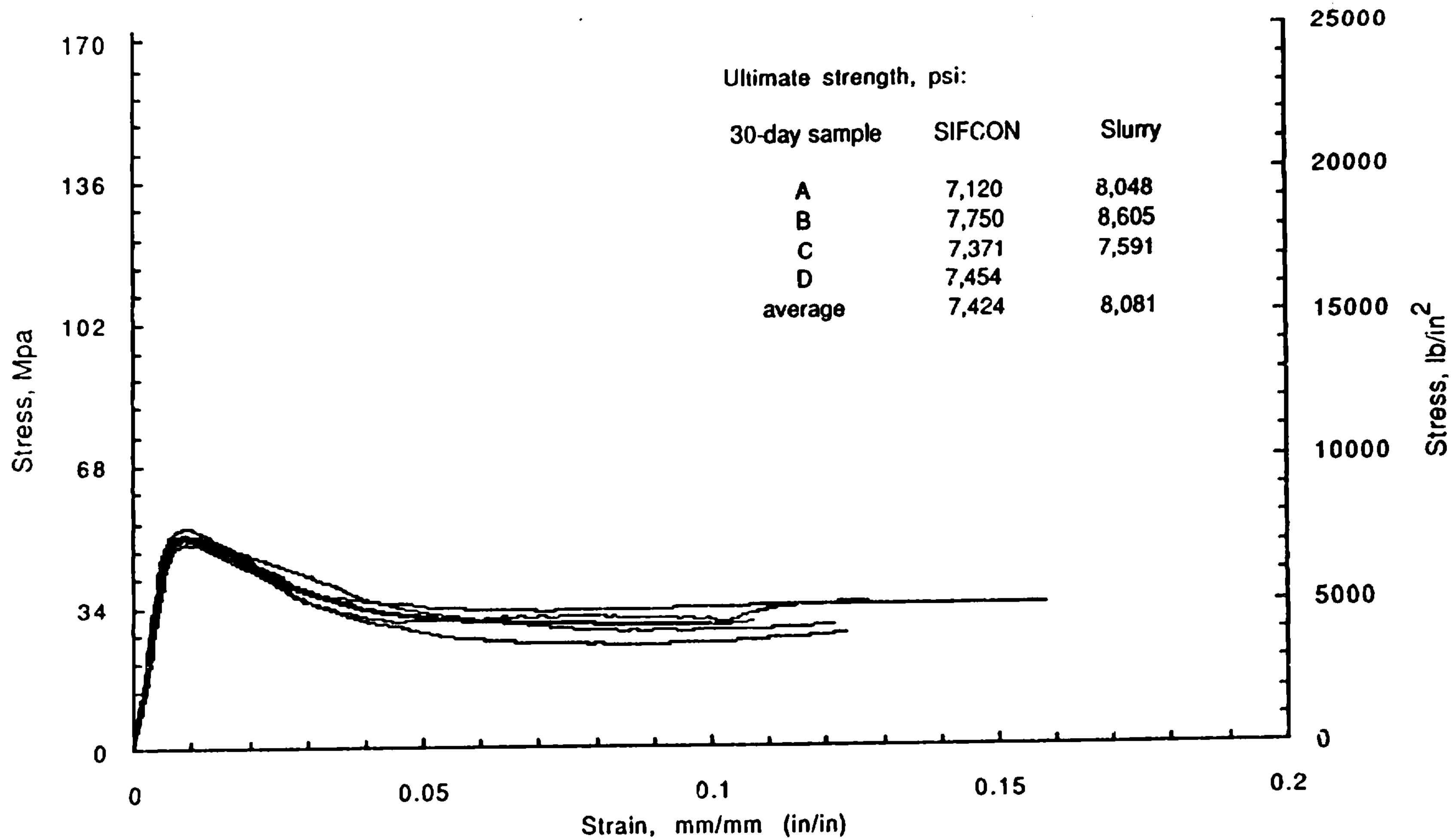


Figure C34. Z 6/8-35-30 F compression.

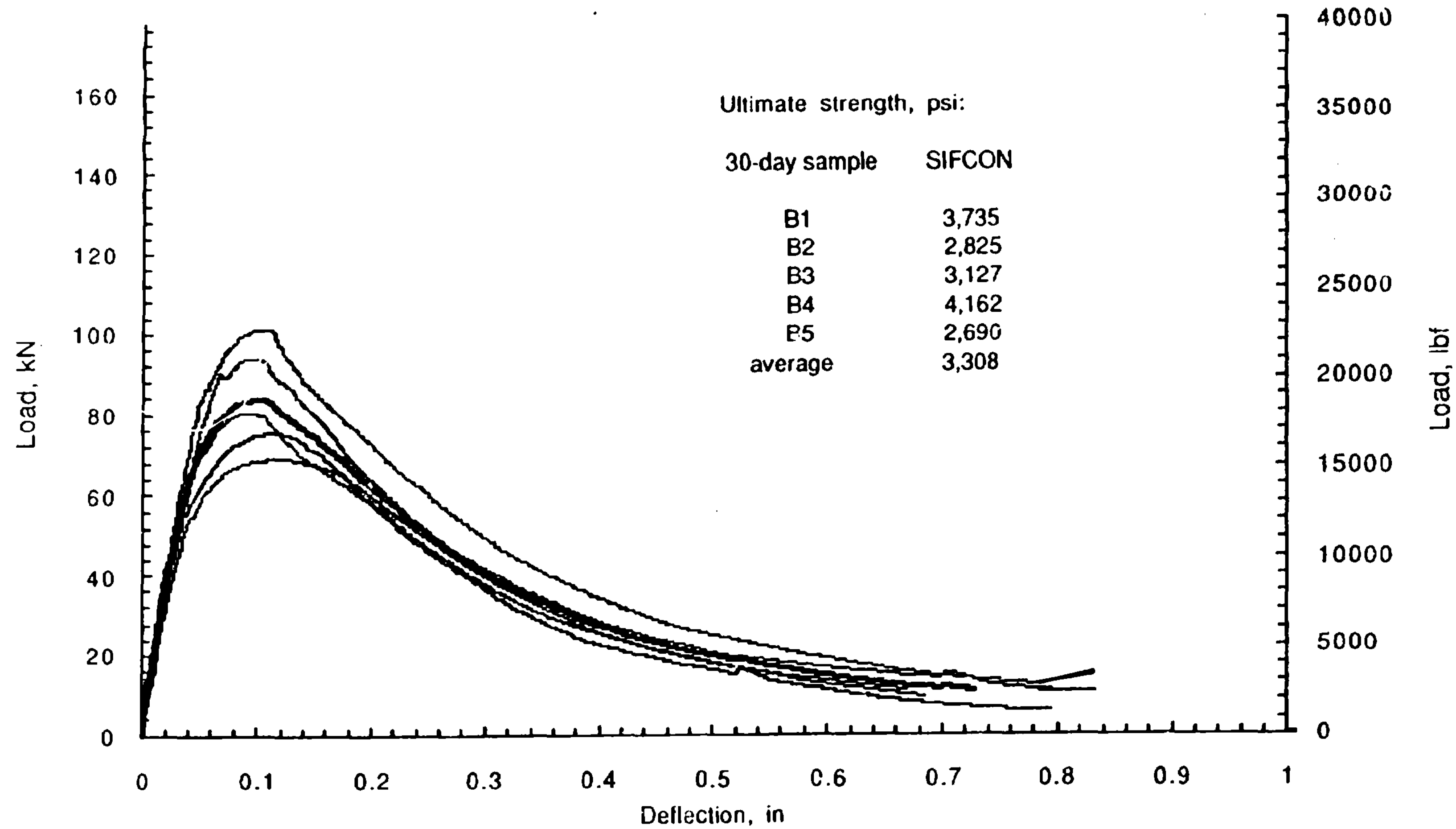


Figure C35. Z 6/8-35-30 F flexure.

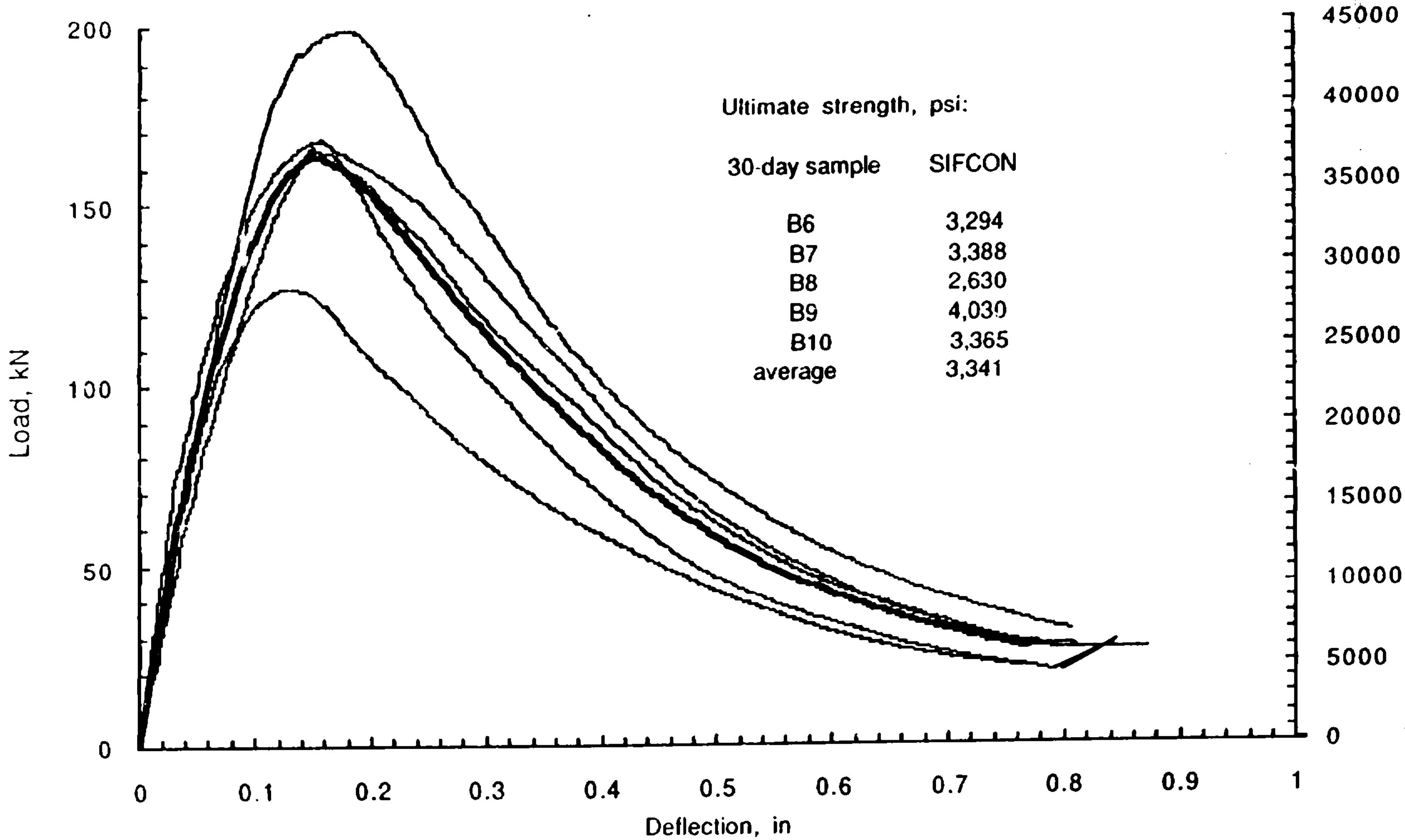


Figure C36. Z 6/8 35-30 F (large) flexure.

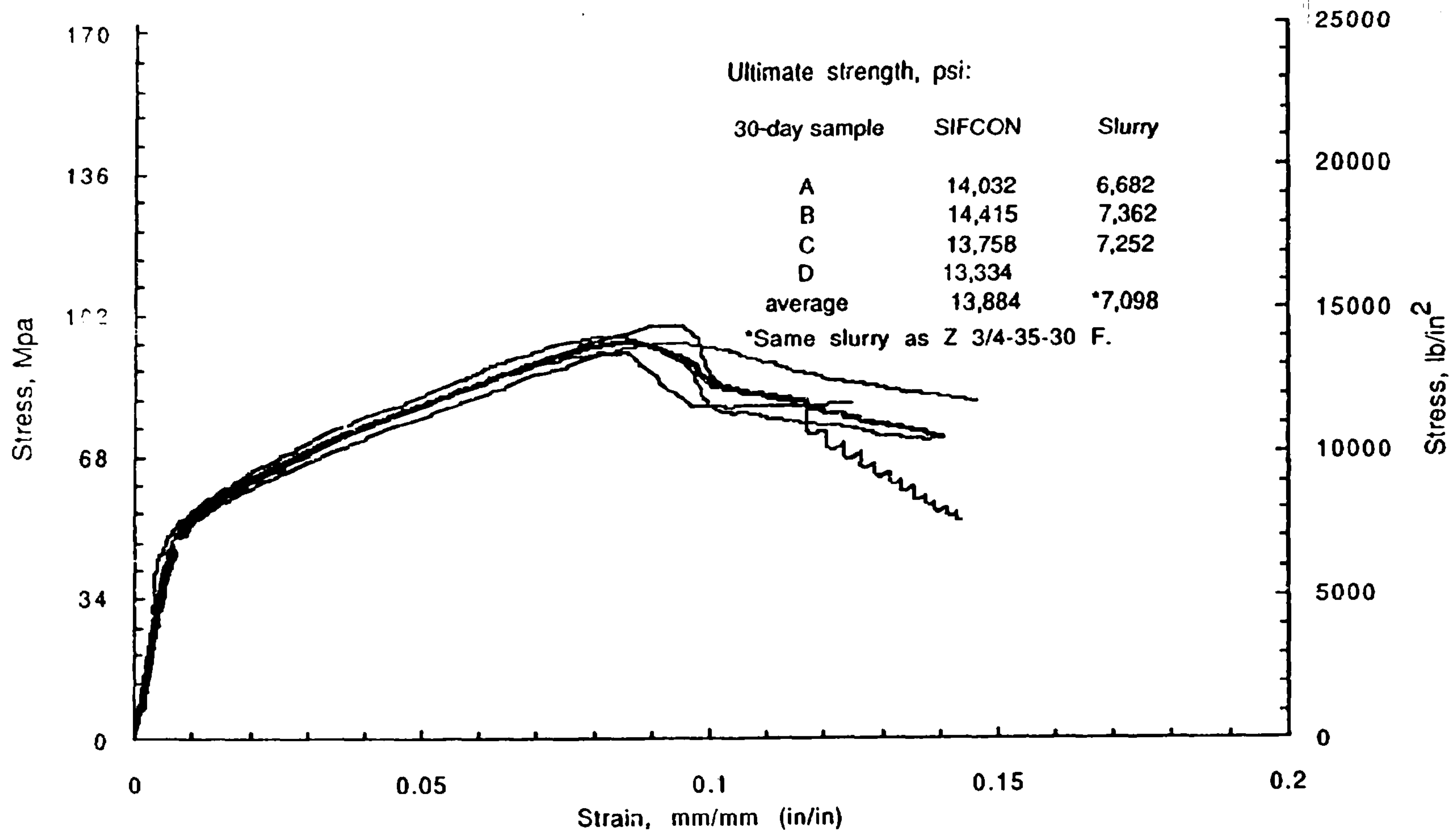


Figure C37. OL 35-30 F compression.

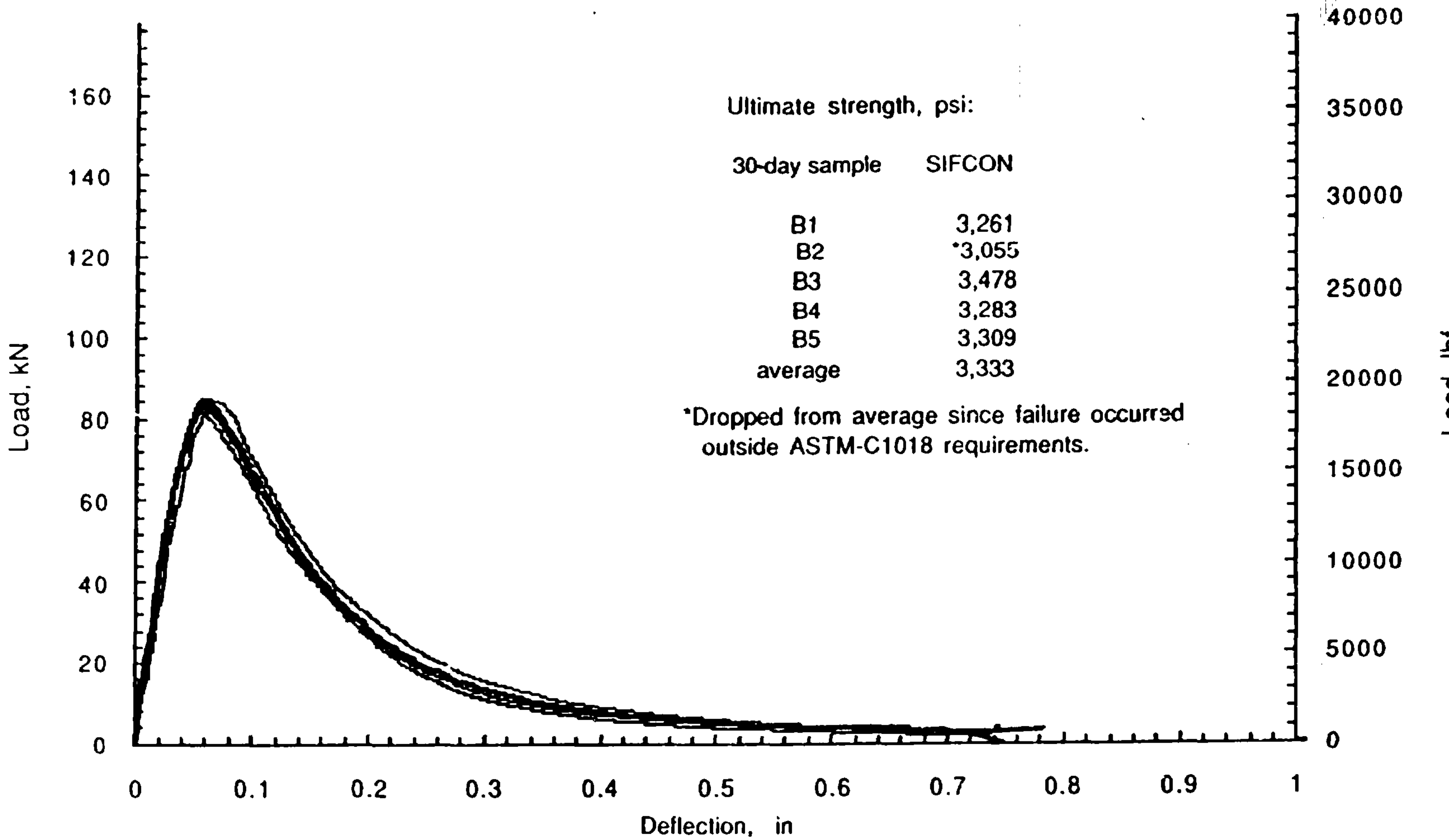


Figure C38. OL 35-30 F flexure.

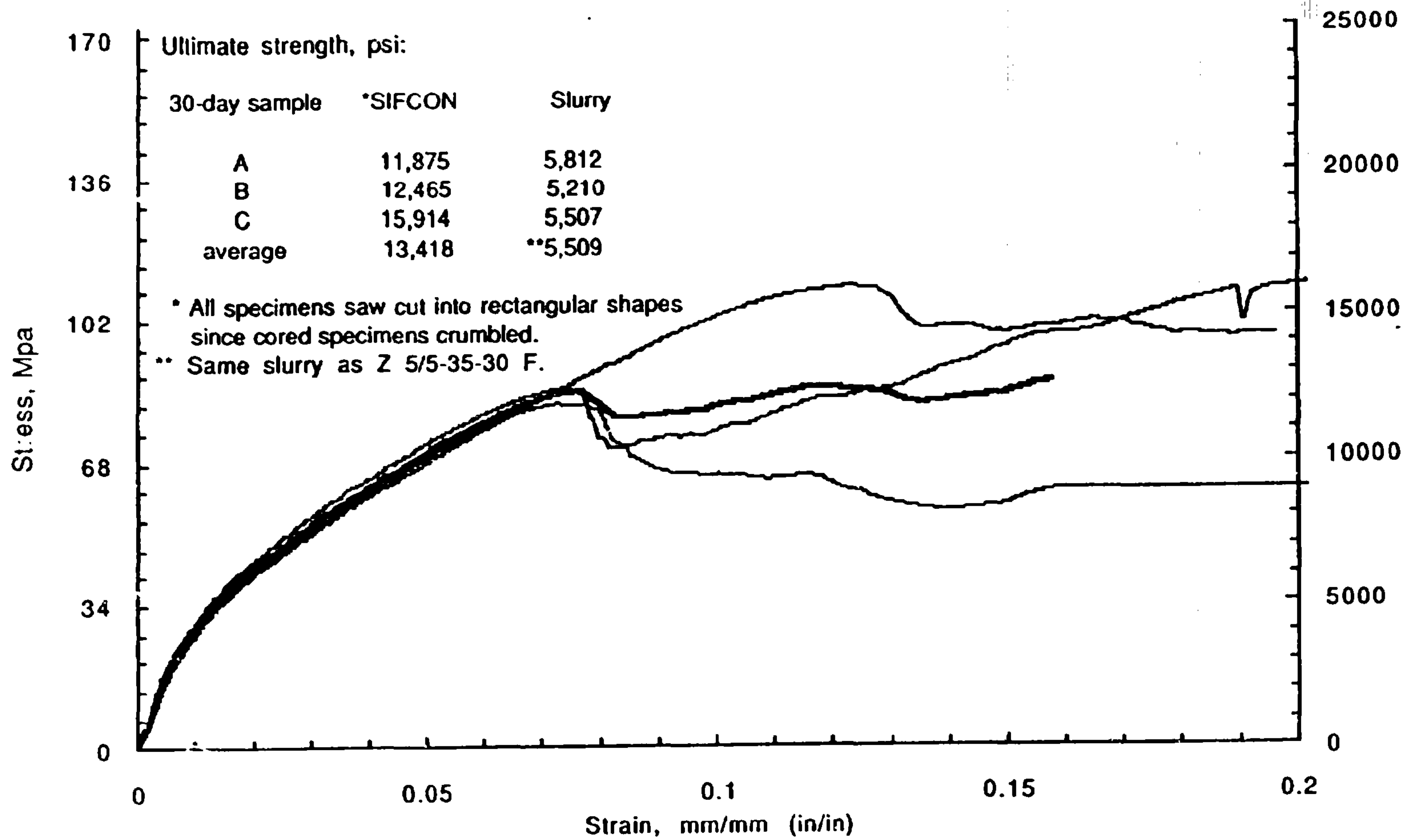


Figure C39. X 11-35-30 F compression.

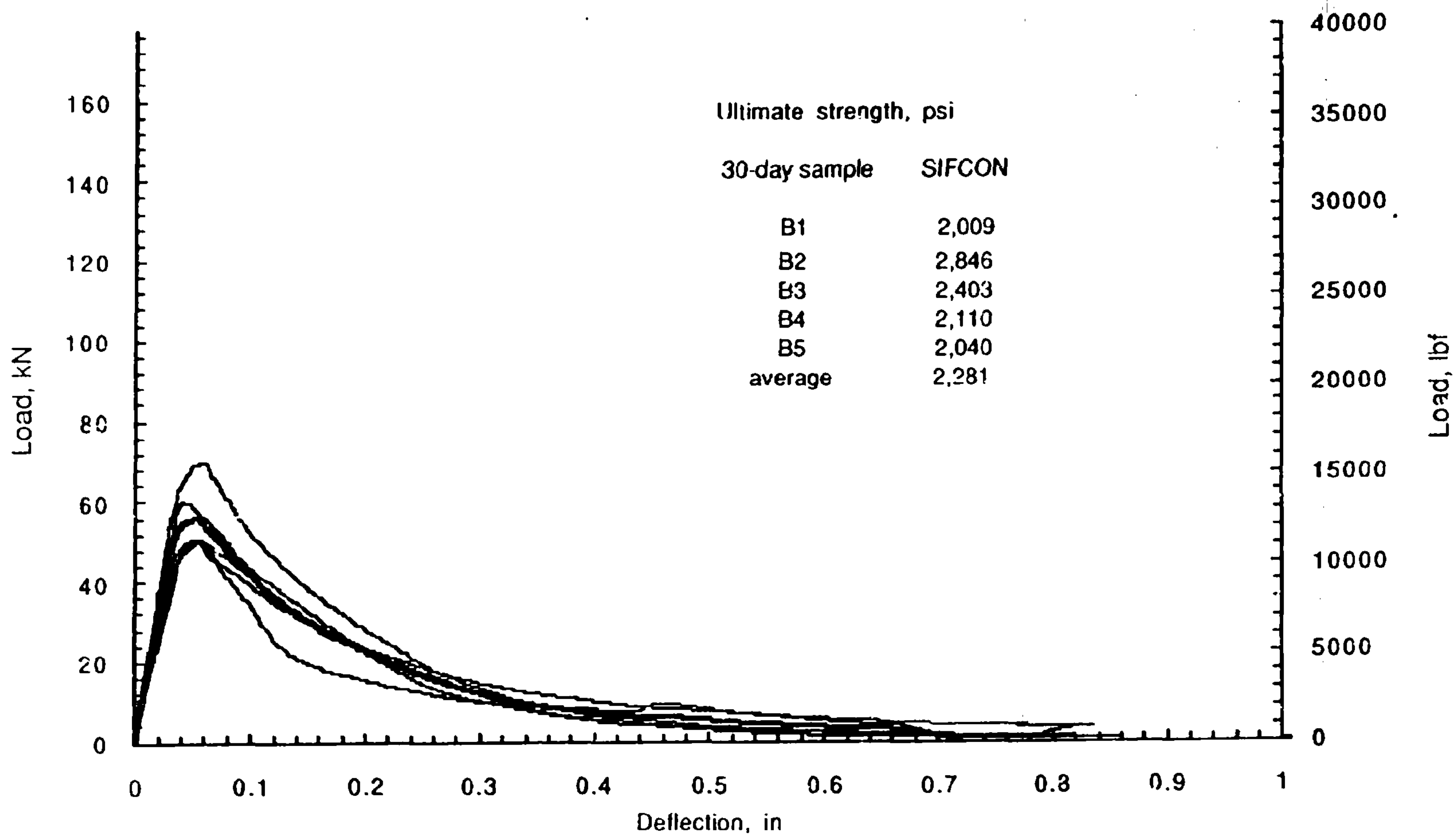


Figure C40 . X 11-35-30 F flexure.

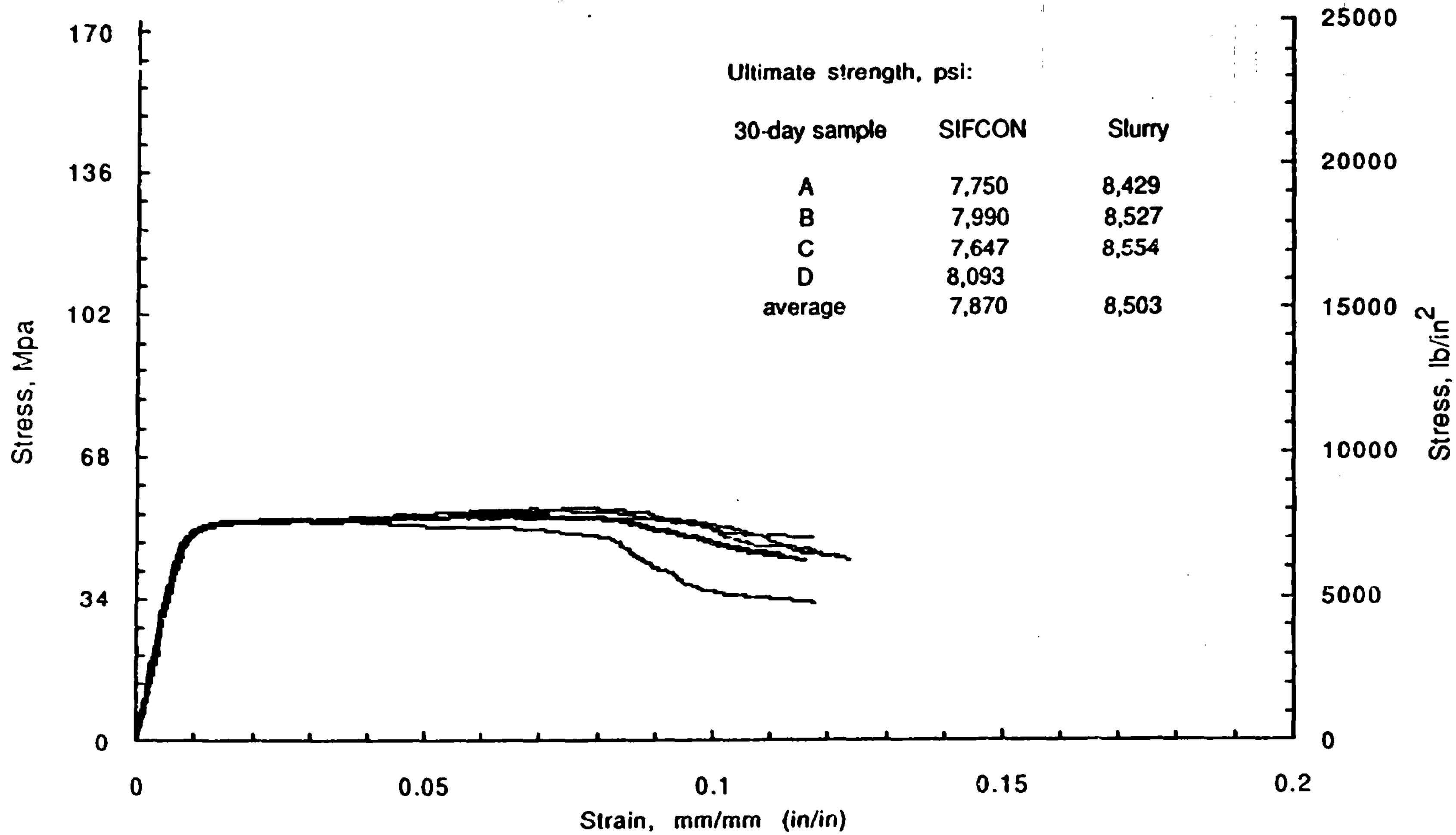


Figure C41. X 12-35-30 F compression.

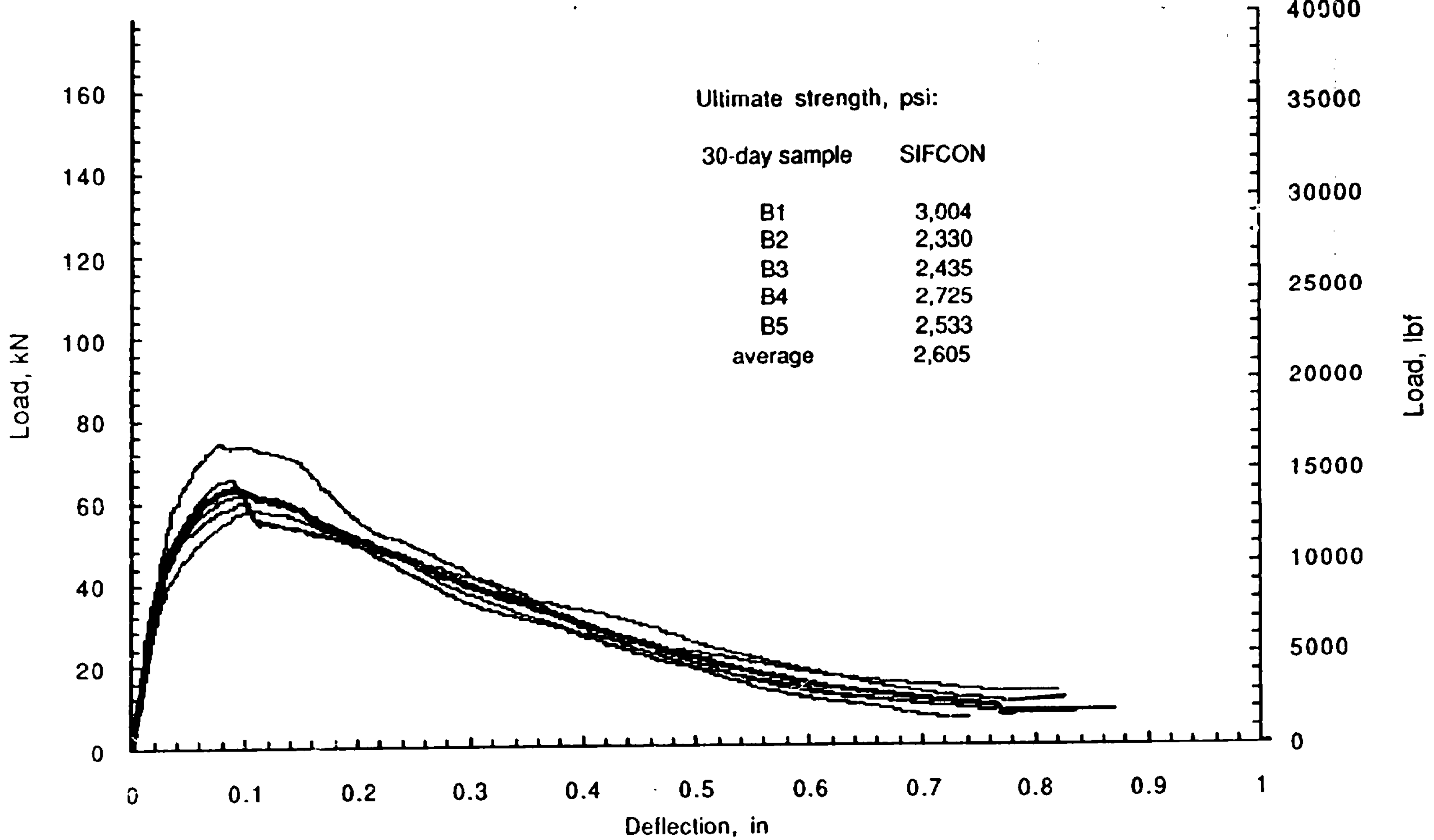


Figure C42. X 12-35-30 F flexure.

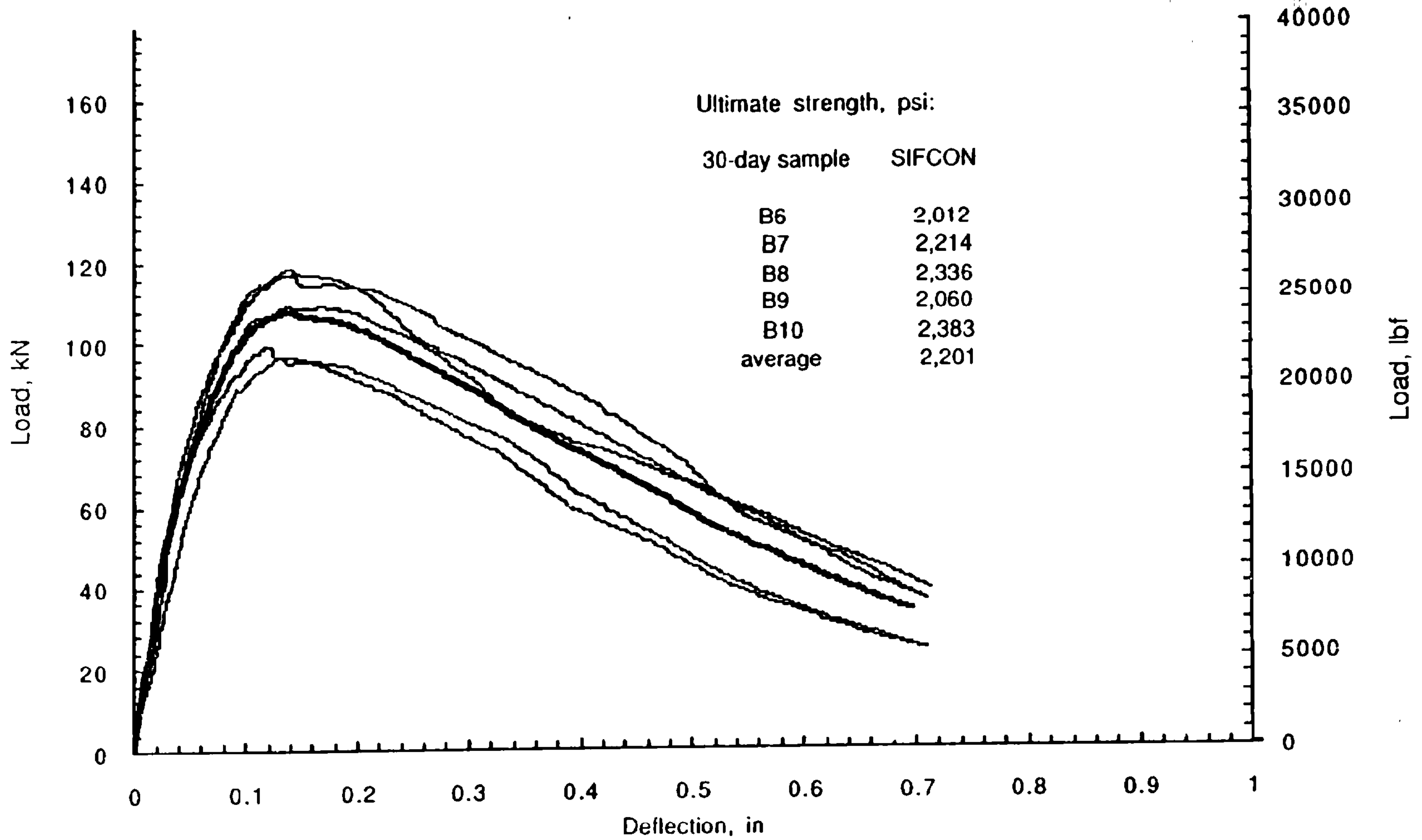


Figure C43. X 12-35-30 F (large) flexure.

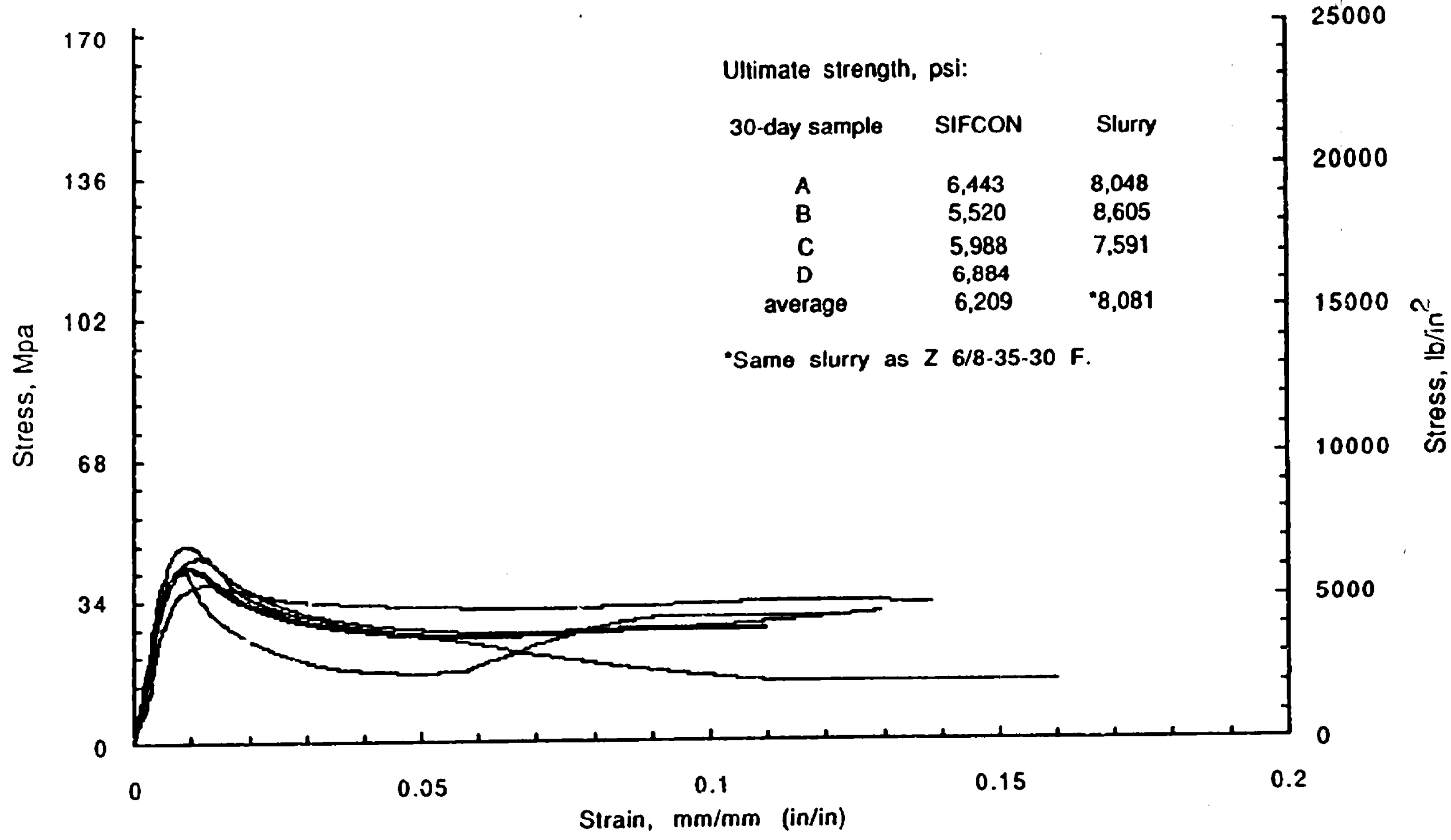


Figure C44. X 21-35-30 F compression.

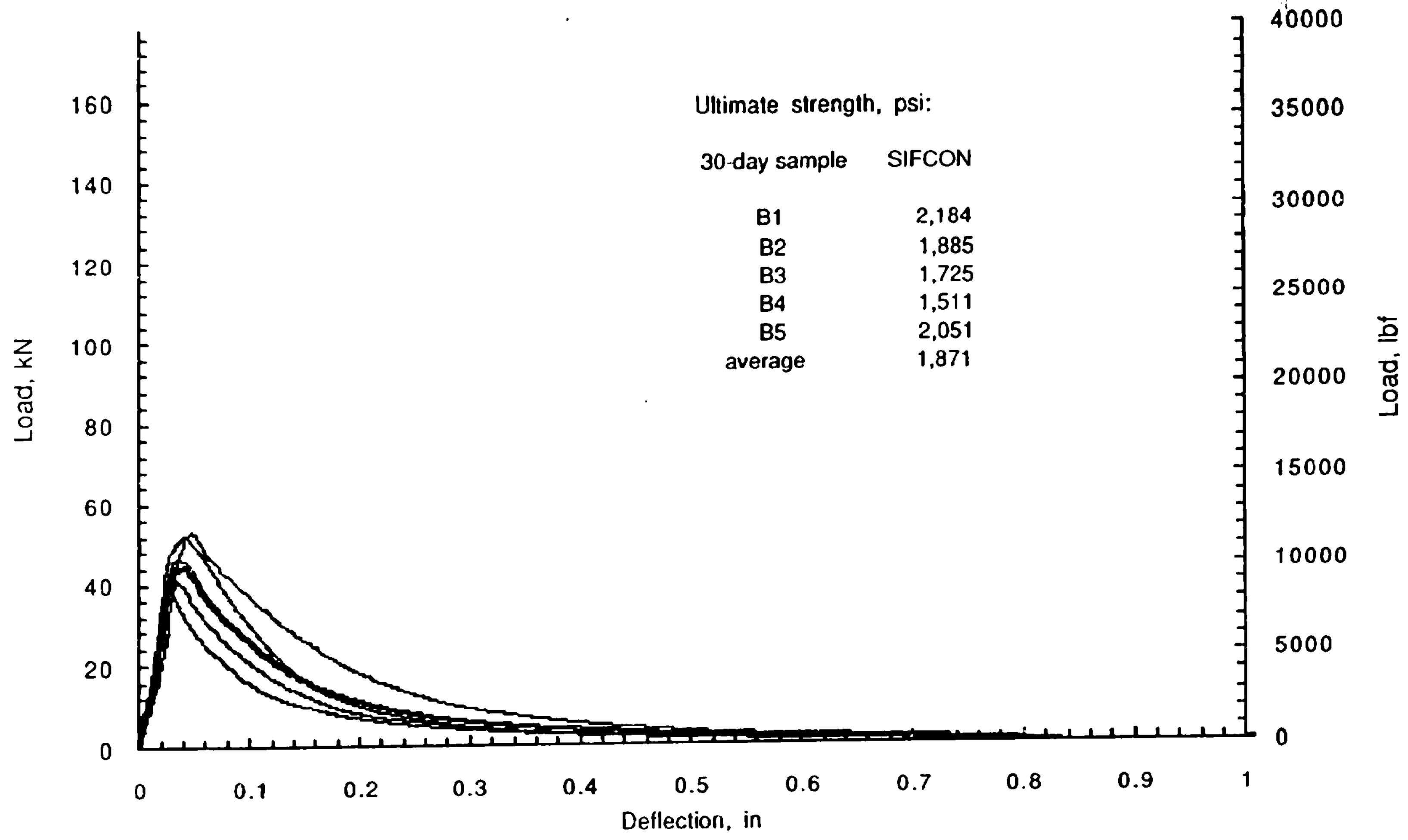


Figure C45. X 21-35-30 F flexure.

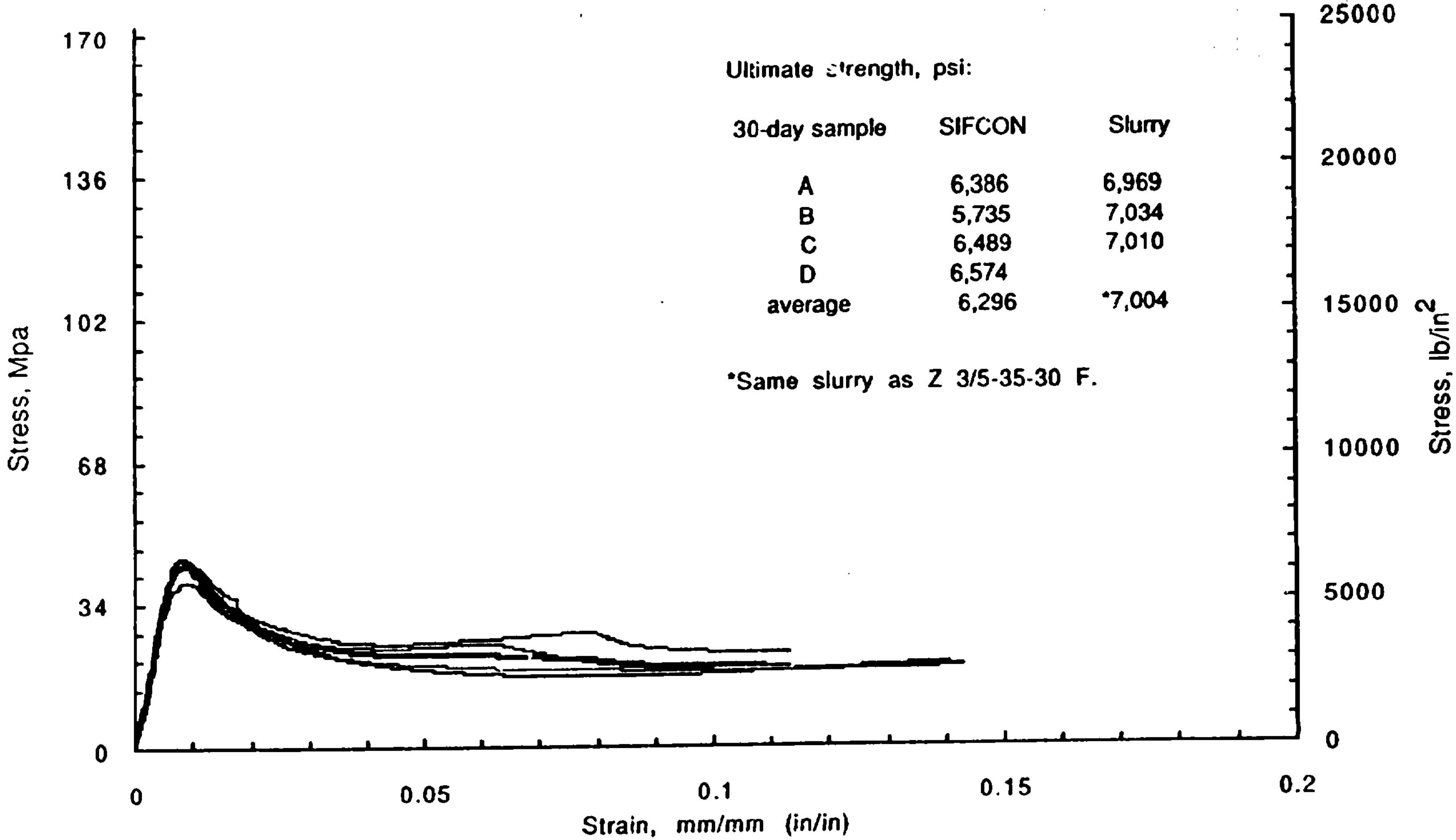


Figure C46. X 22-35-30 F compression.

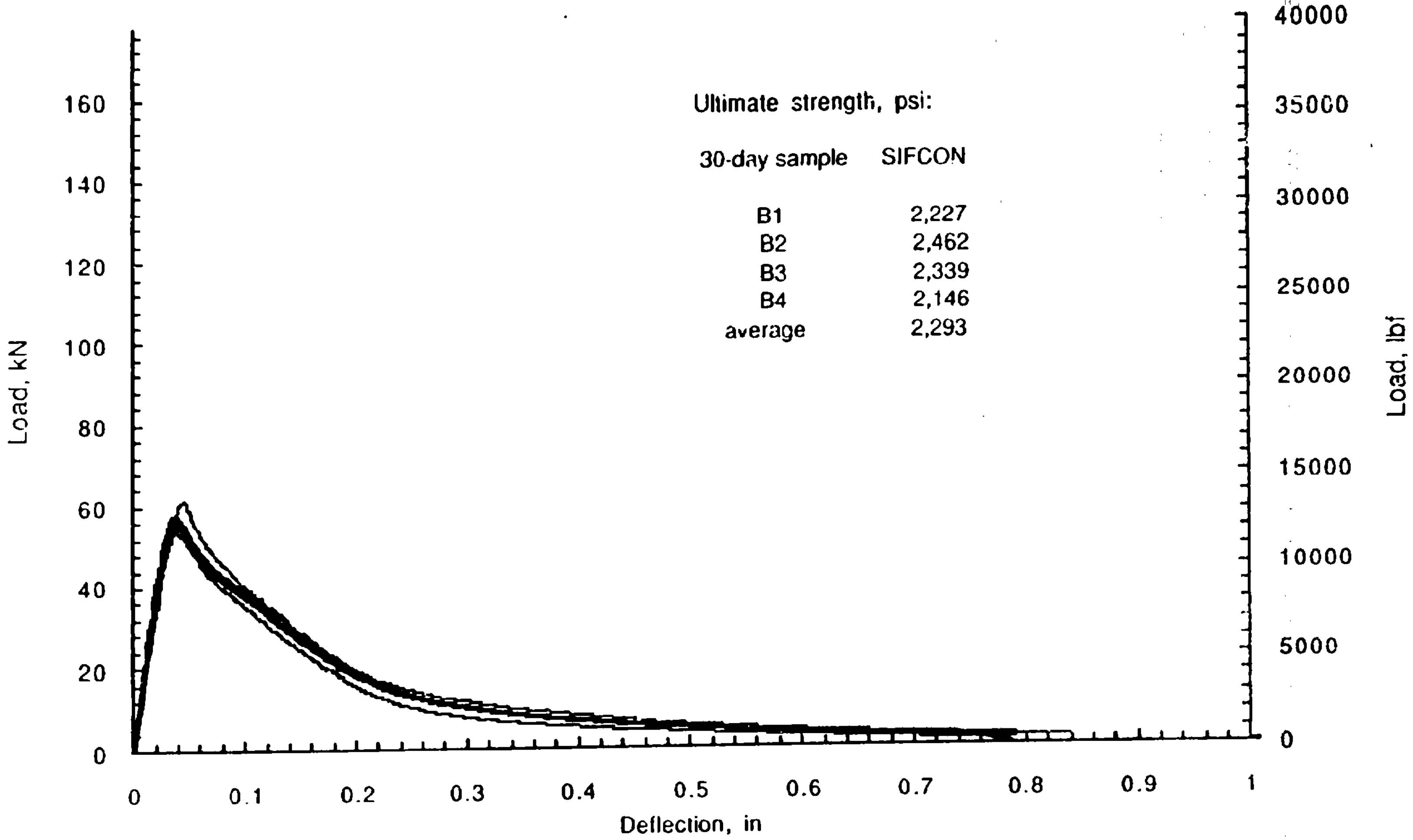


Figure C47. X 22-35-30 F flexure.

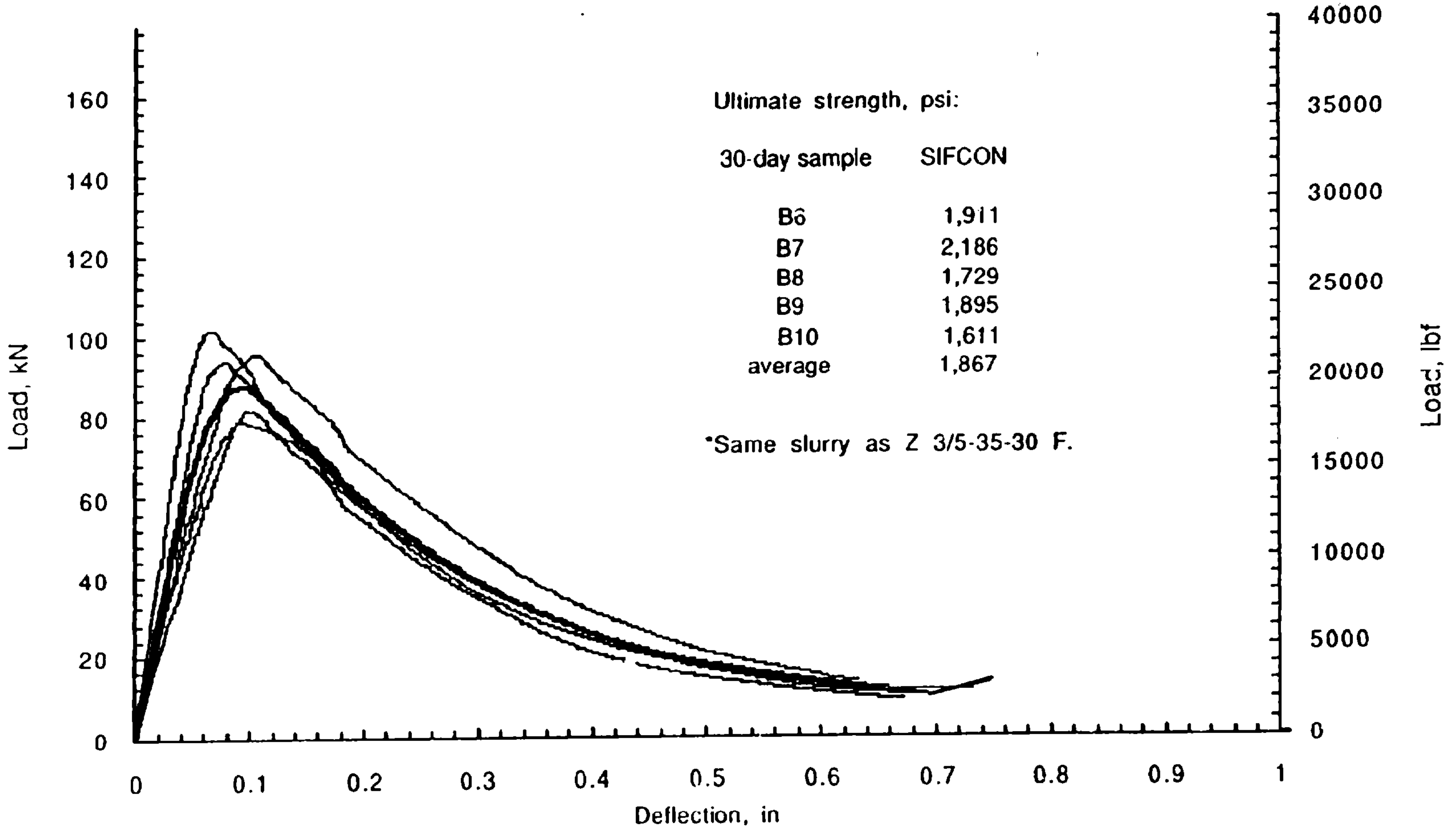


Figure C48. X 22-35-30 (large) flexure.

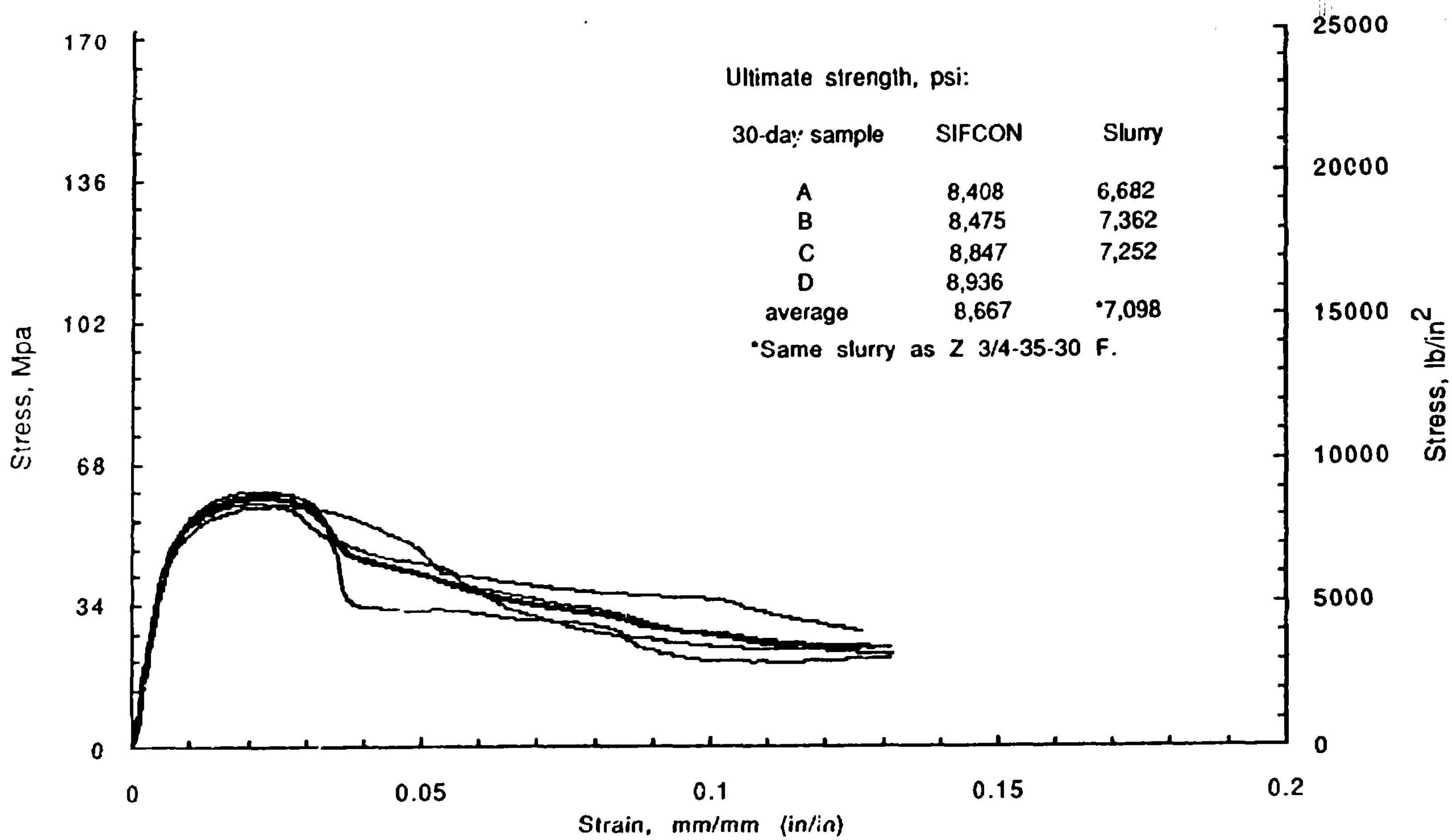


Figure C49. FB 35-30 F compression.

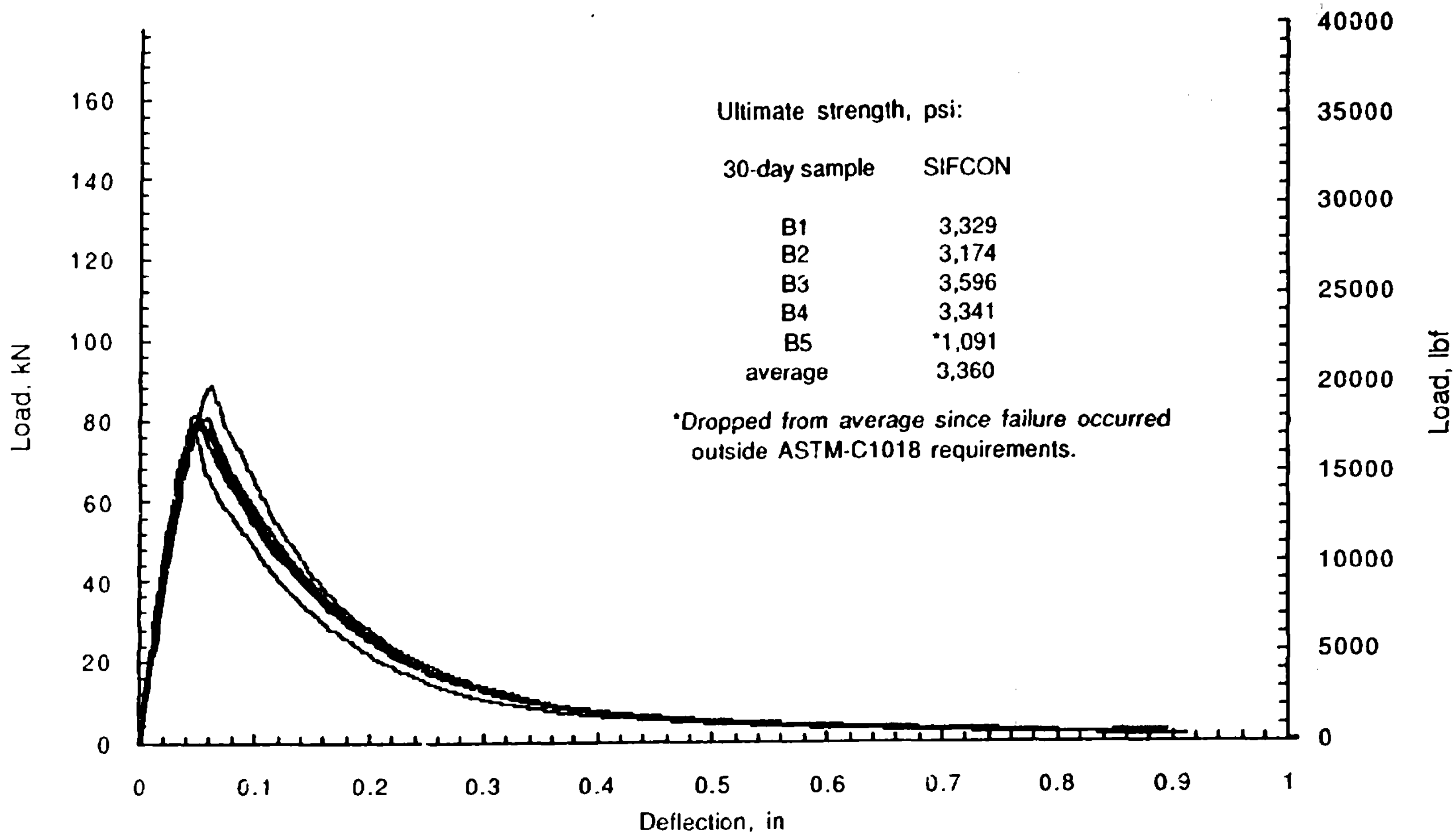


Figure C50. FB 35-30 F flexure.

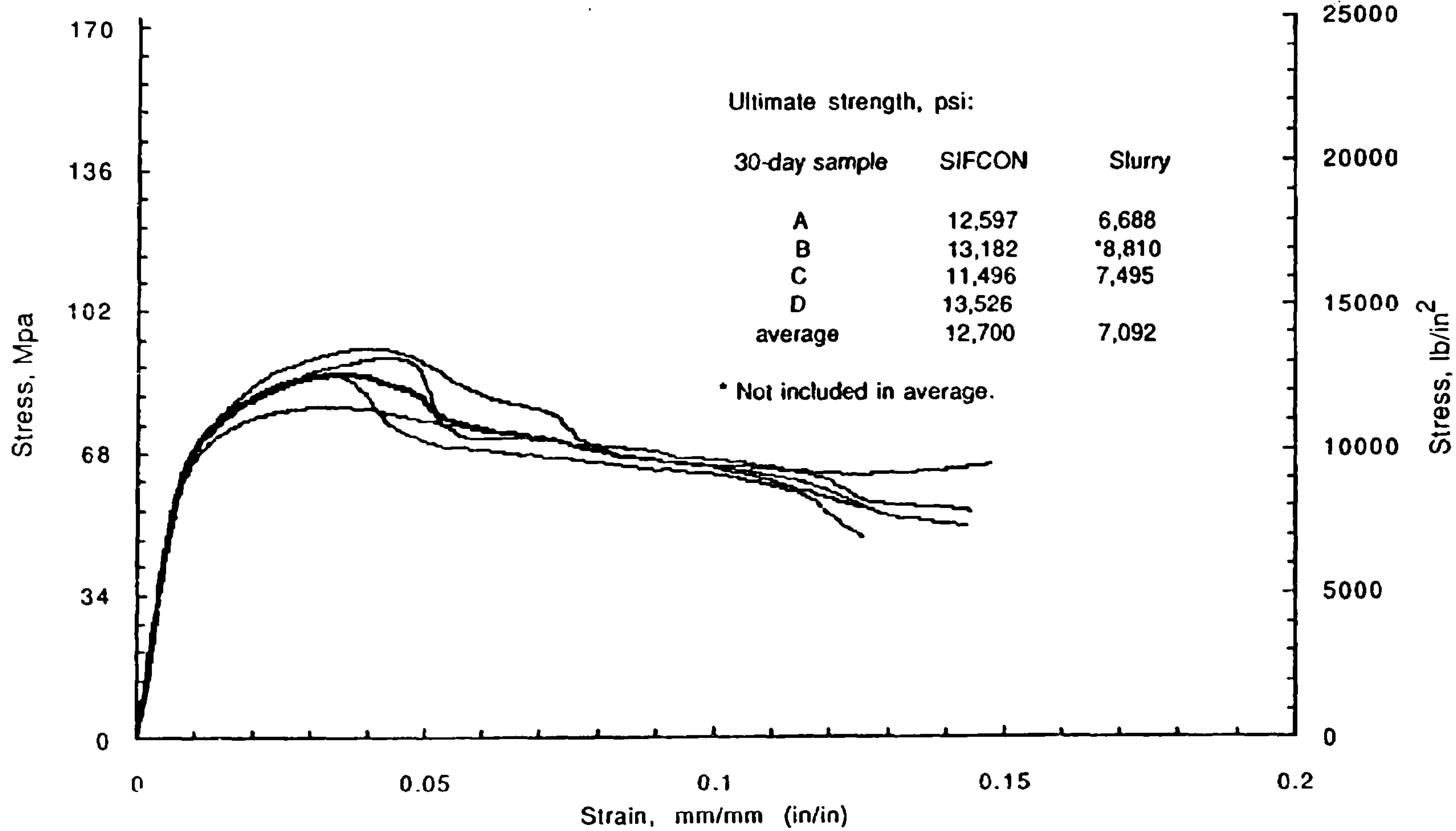


Figure C51. S 25-30-30 F compression.

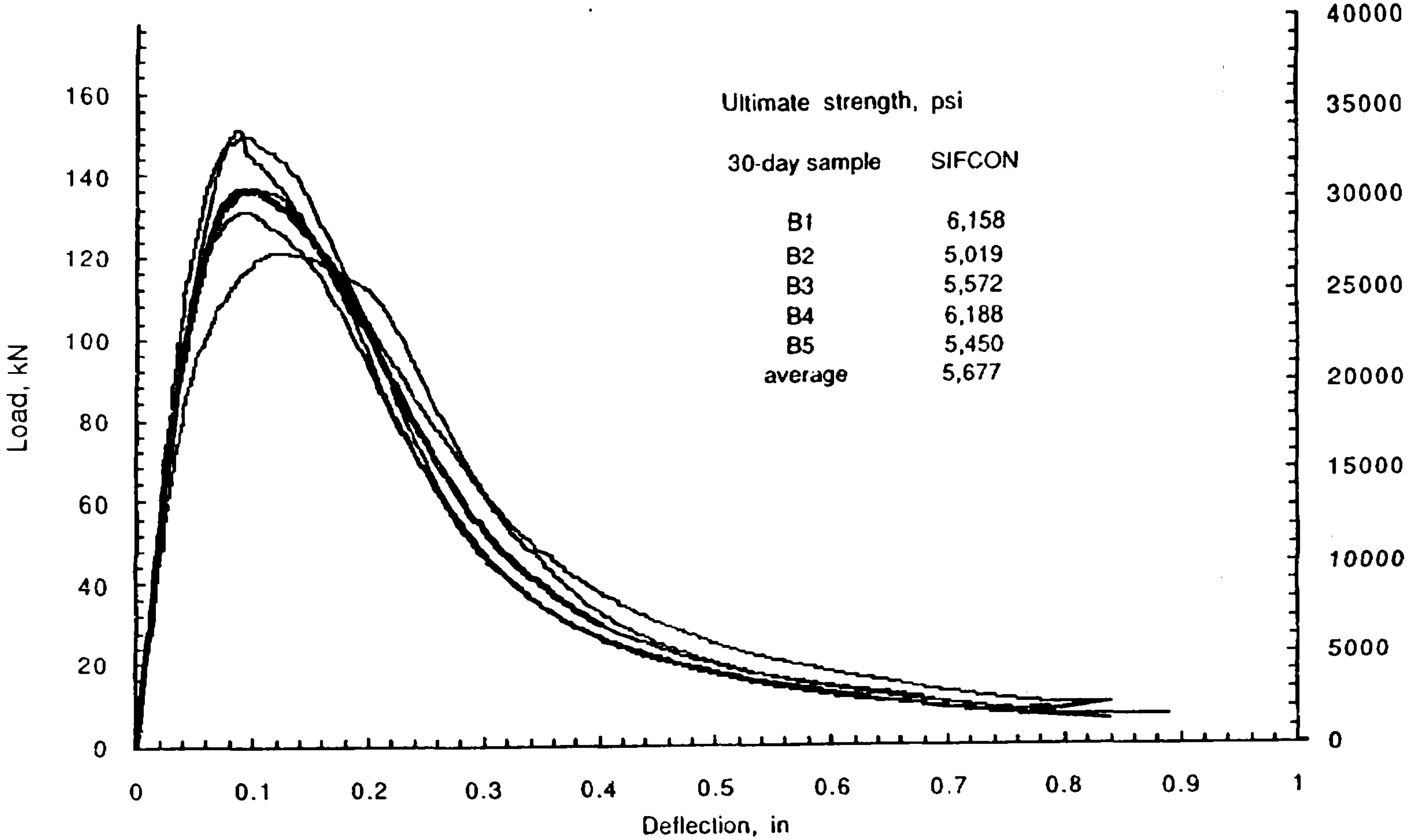


Figure C52. S 25-30-30 F flexure.

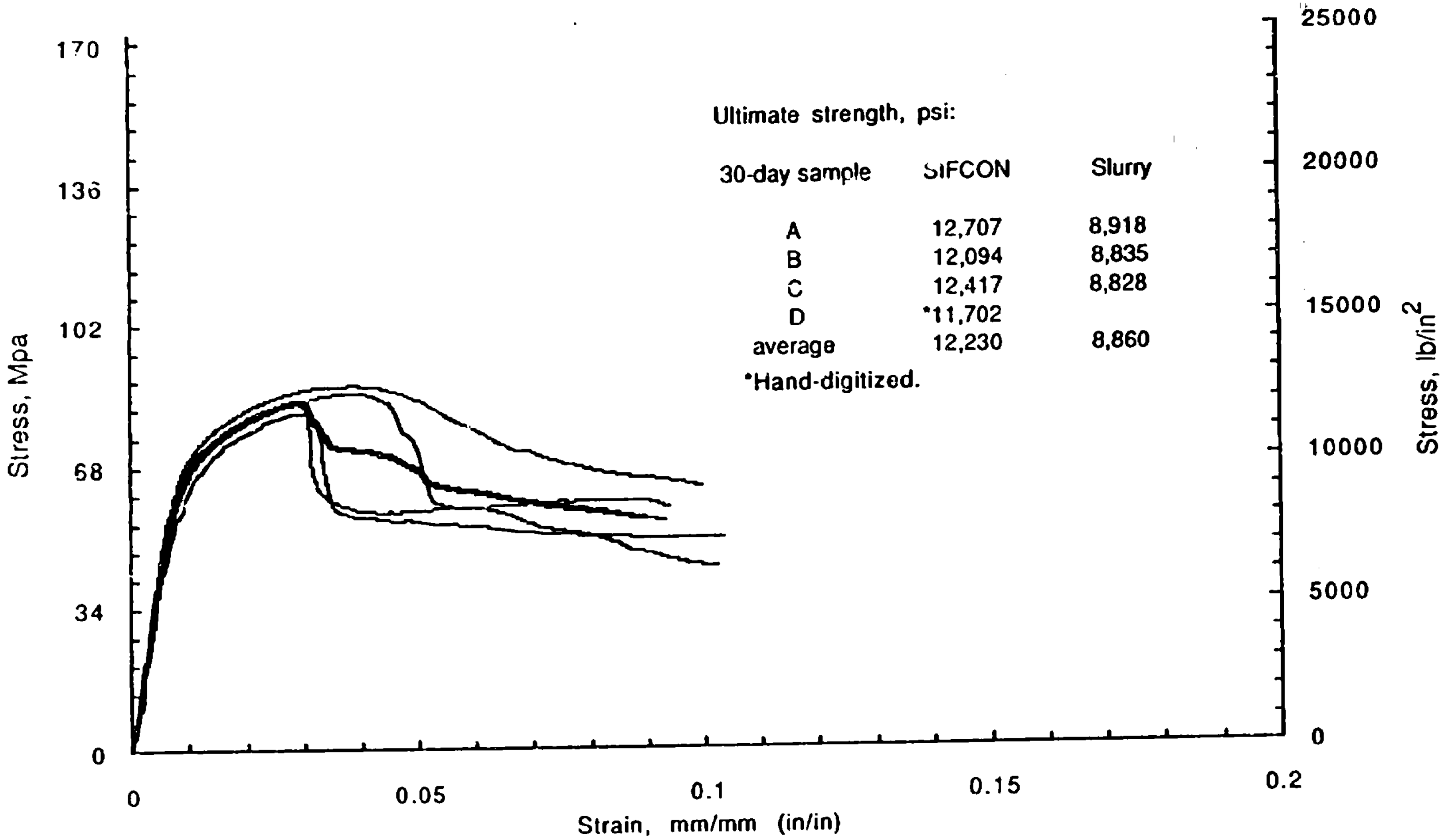


Figure C53. S 50-30-30 F compression.

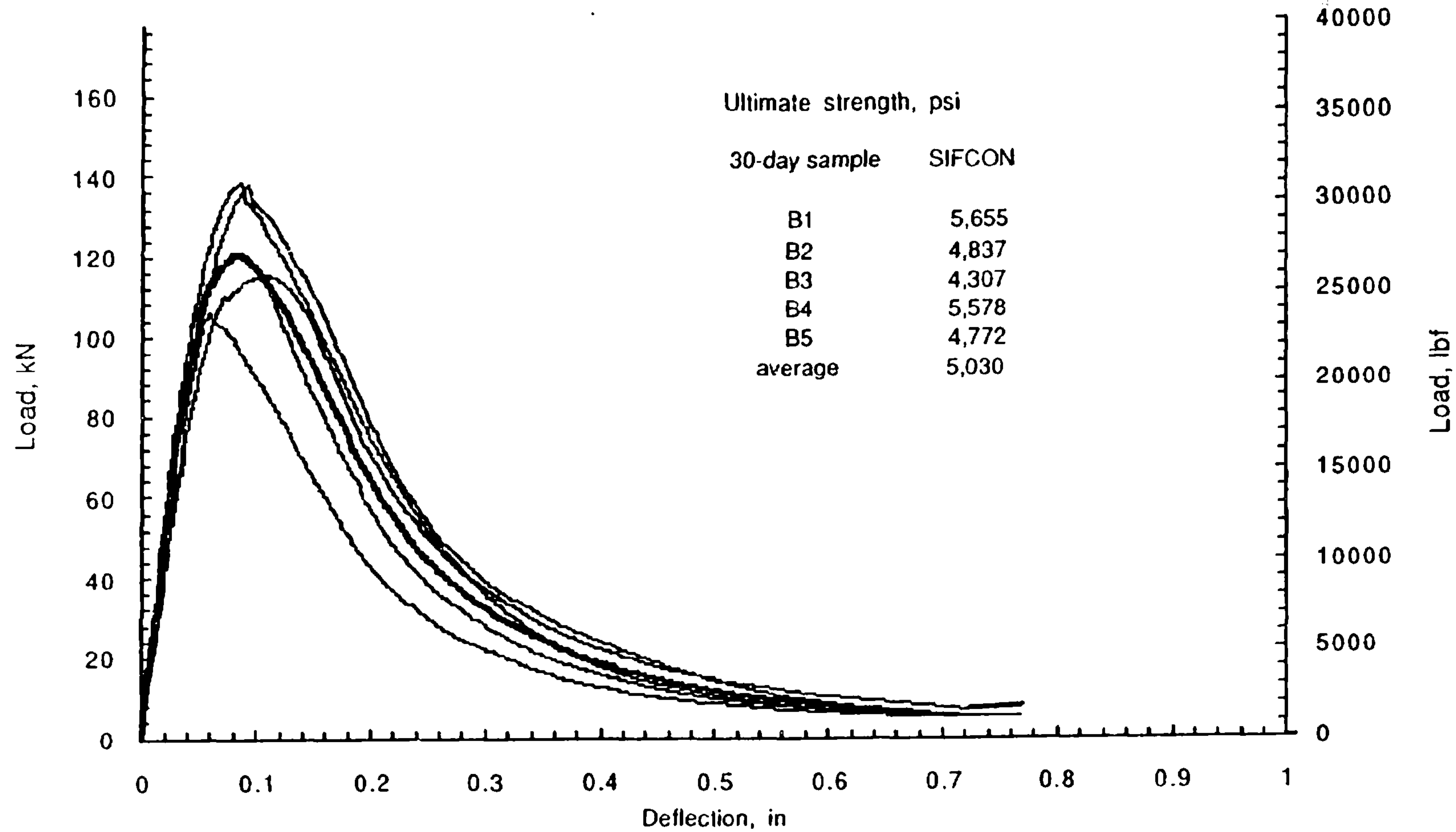


Figure C54. S 50-30-30 F flexure.

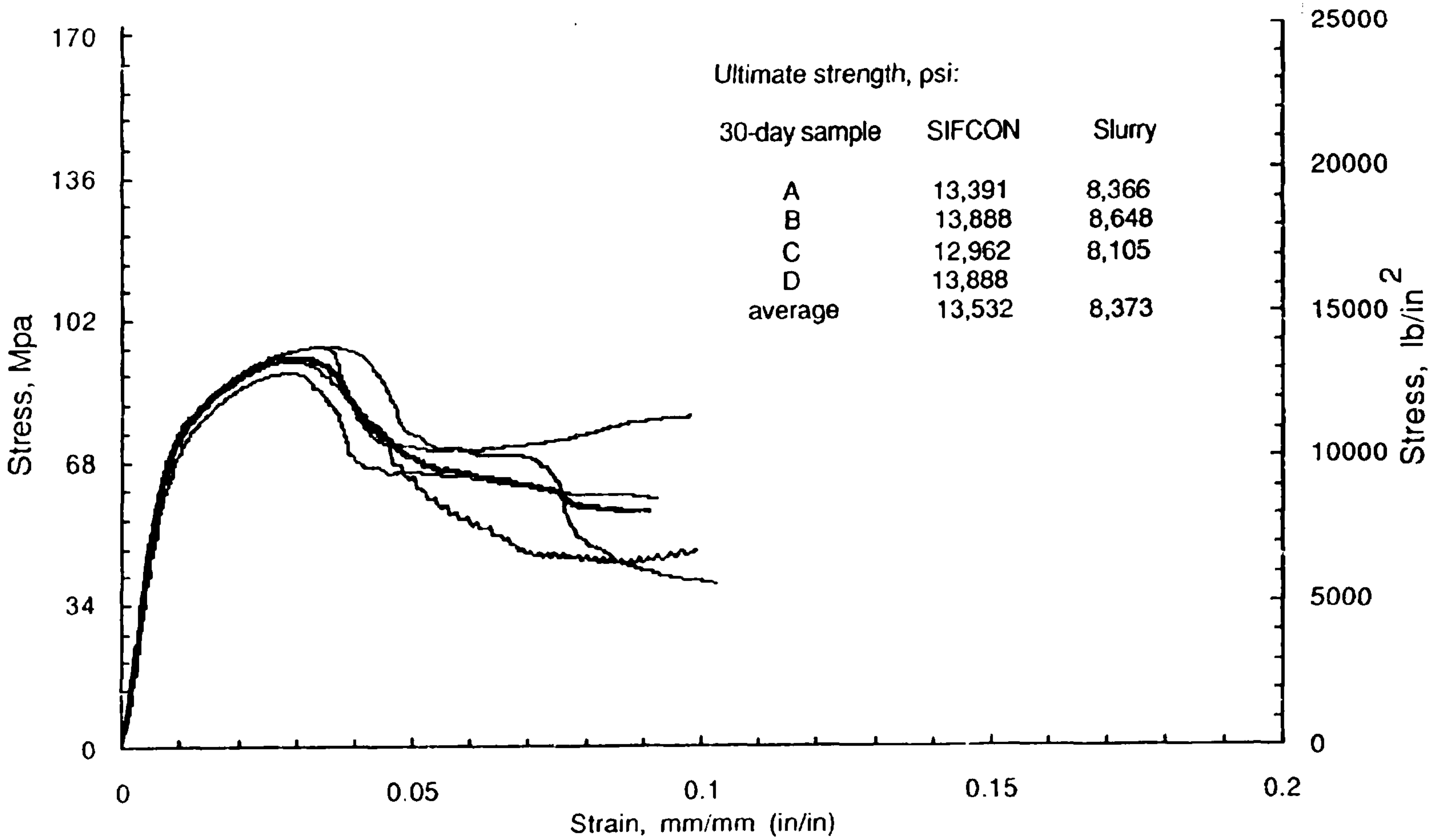


Figure C55. S 75-30-30 F compression.

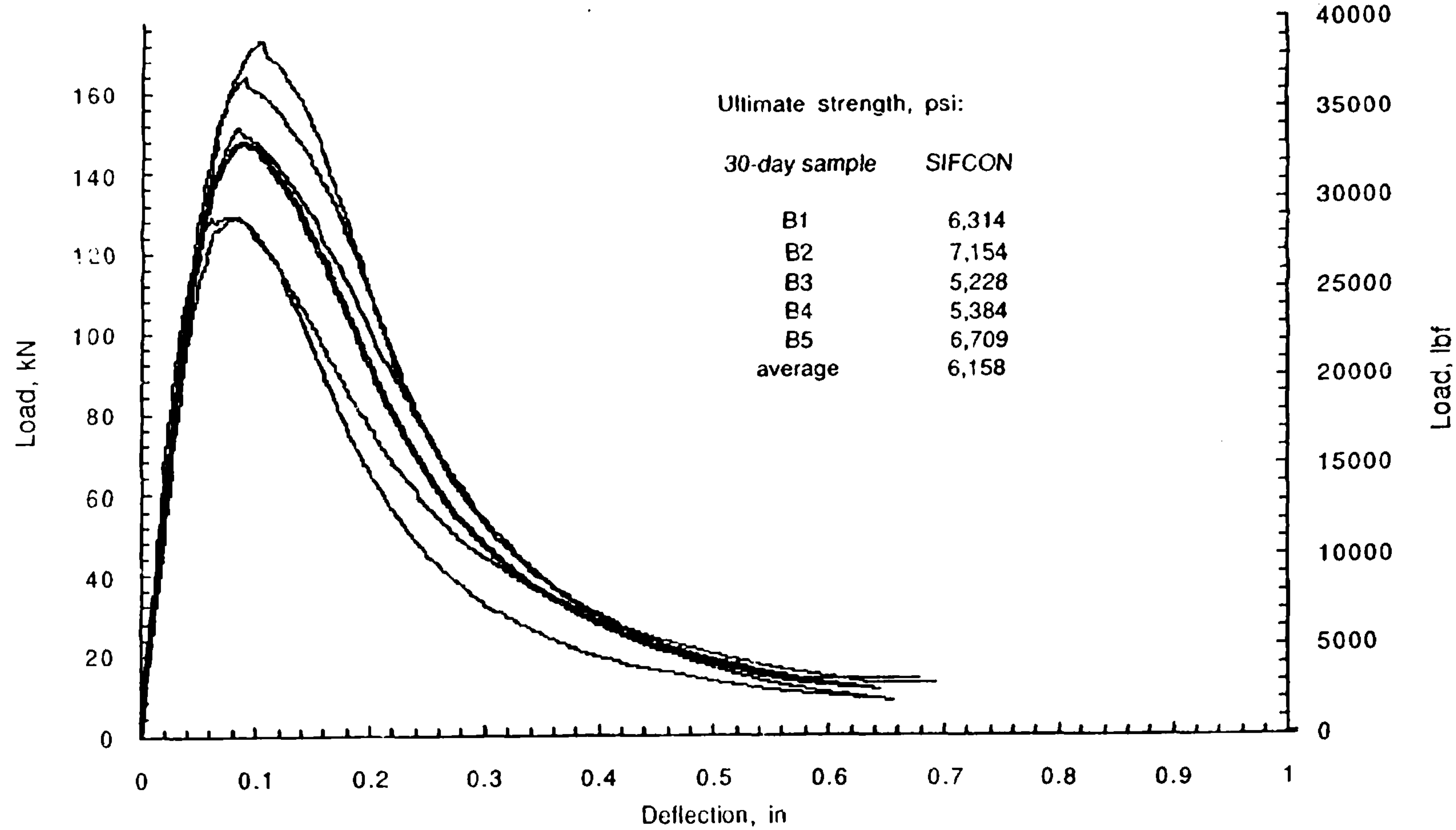


Figure C56. S 75-30-30 F flexure.

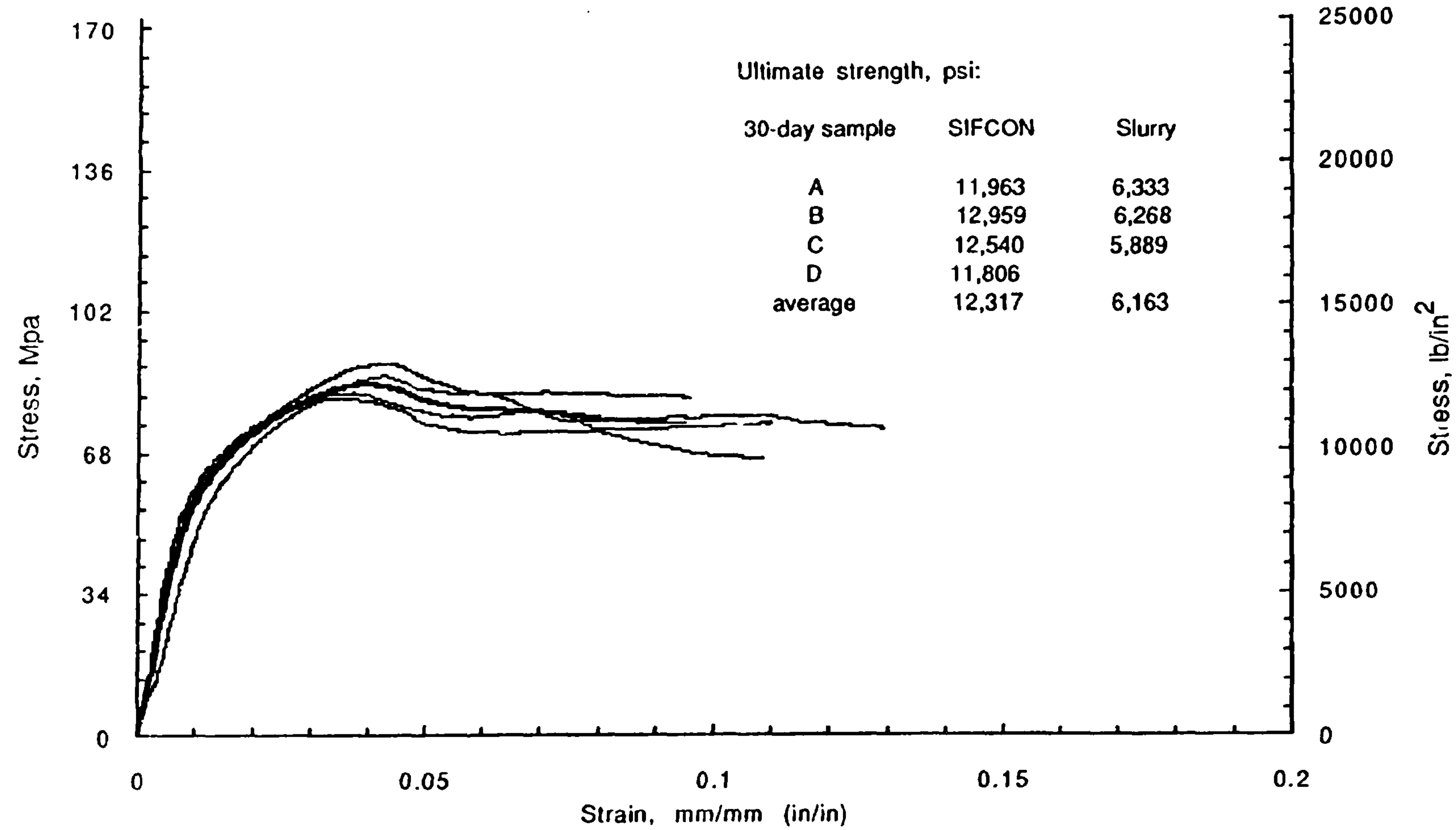


Figure C57. S 50-40-30 F compression.

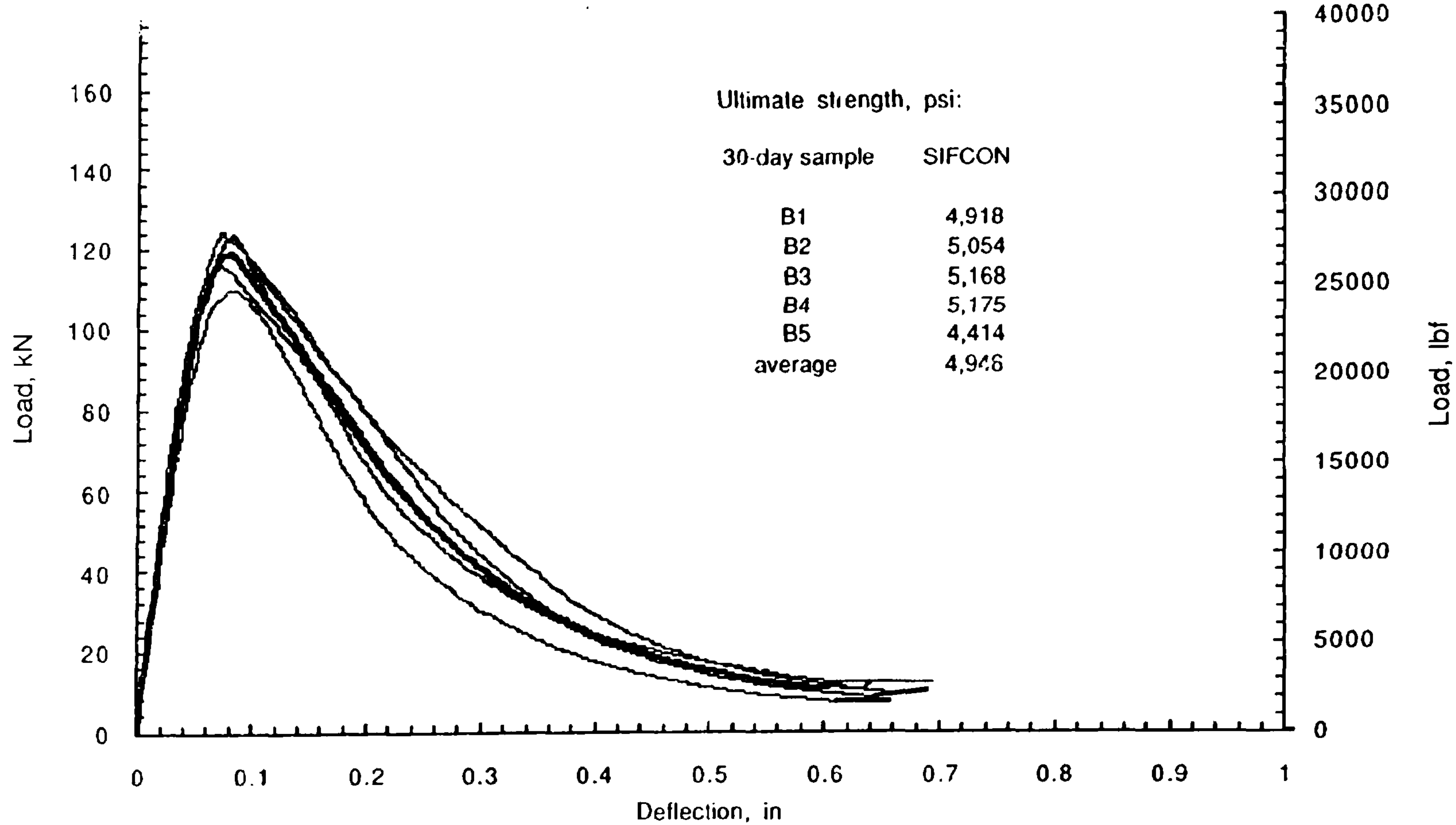


Figure C58. S 50-40-30 F flexure.

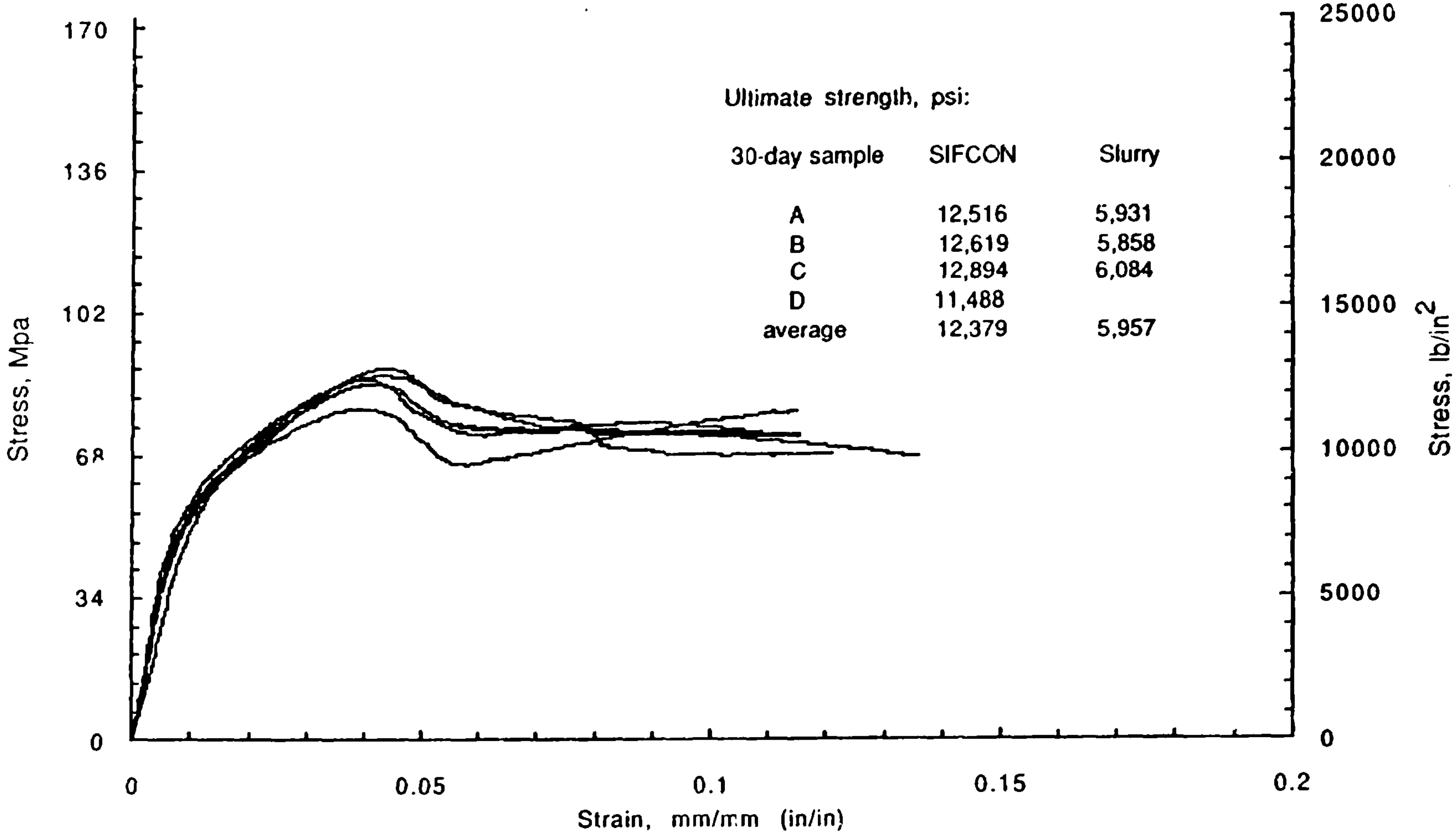


Figure C59. S 100-40-30 F compression.

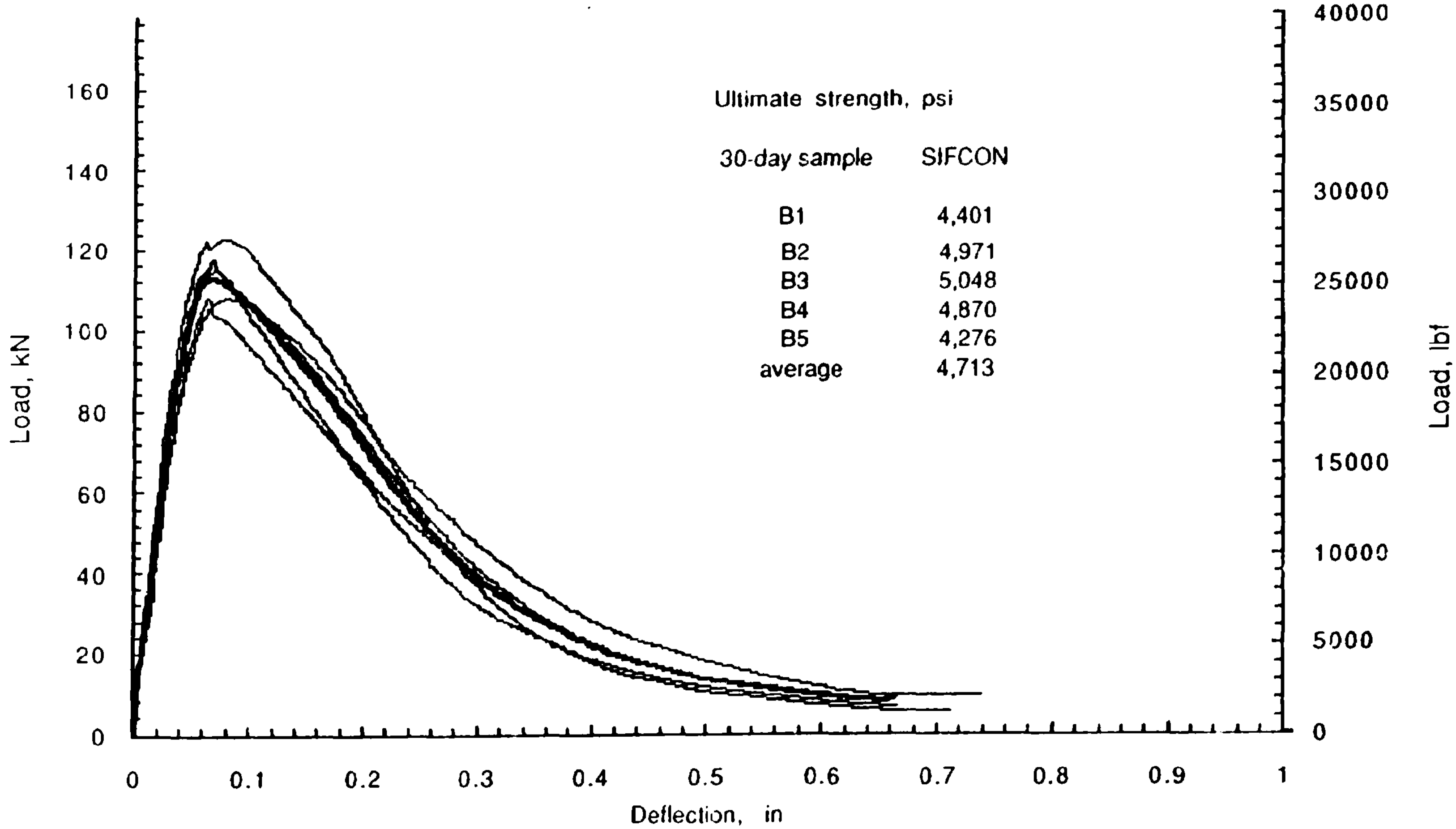


Figure C60. S 100-40-30 F flexure.

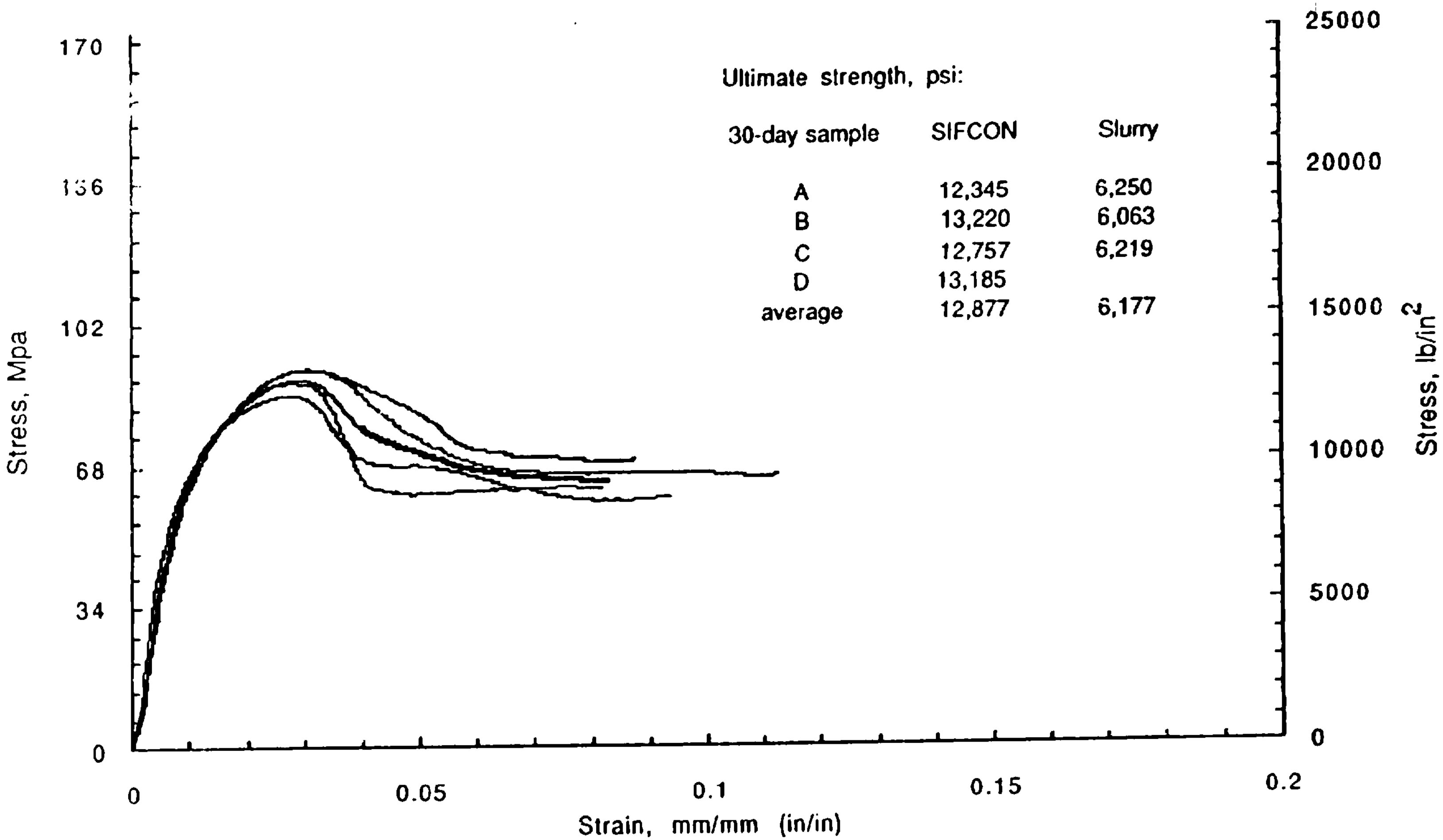


Figure C61. S 150-40-30 F compression.

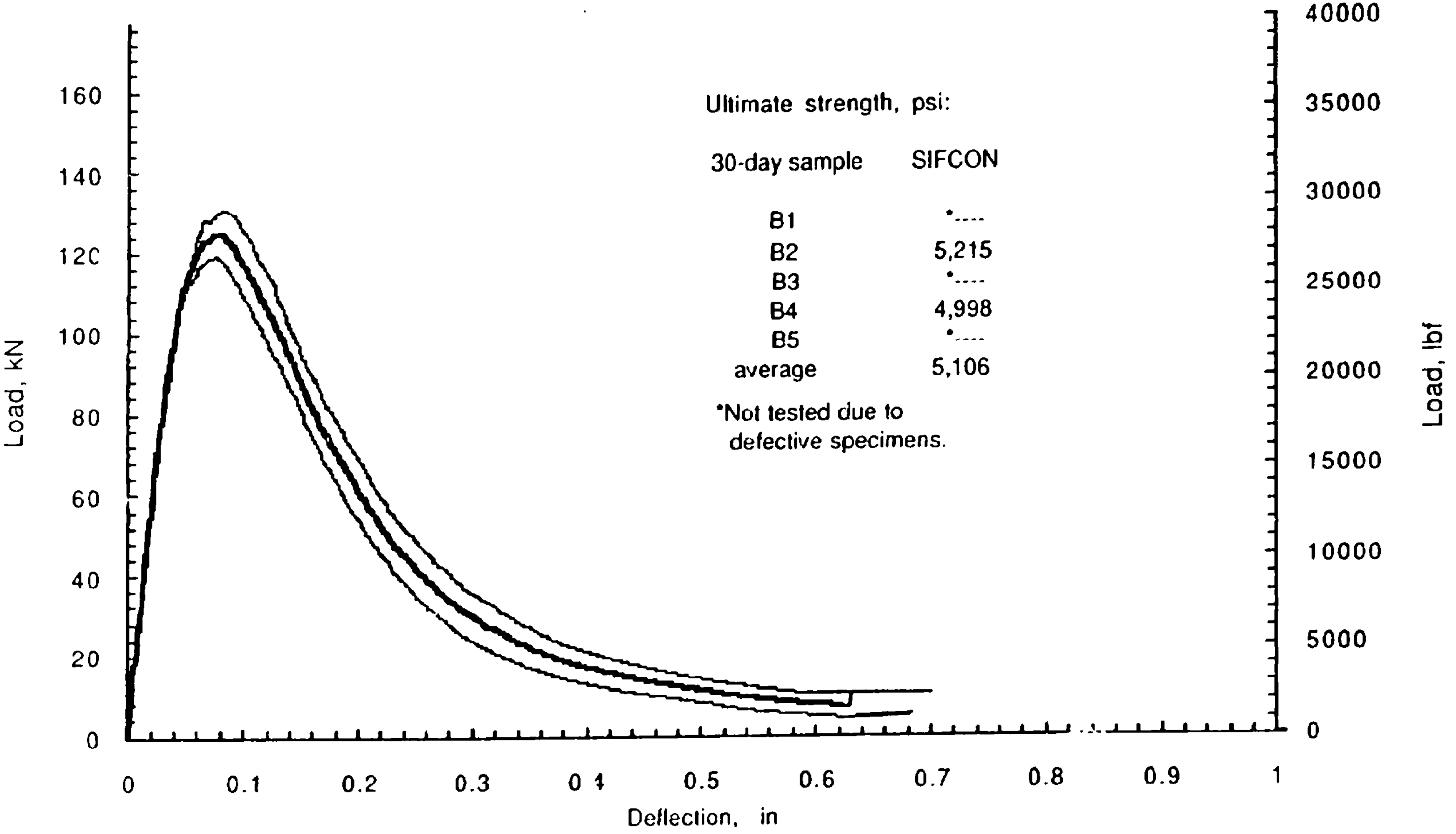


Figure C62. S 150-40-30 F flexure.

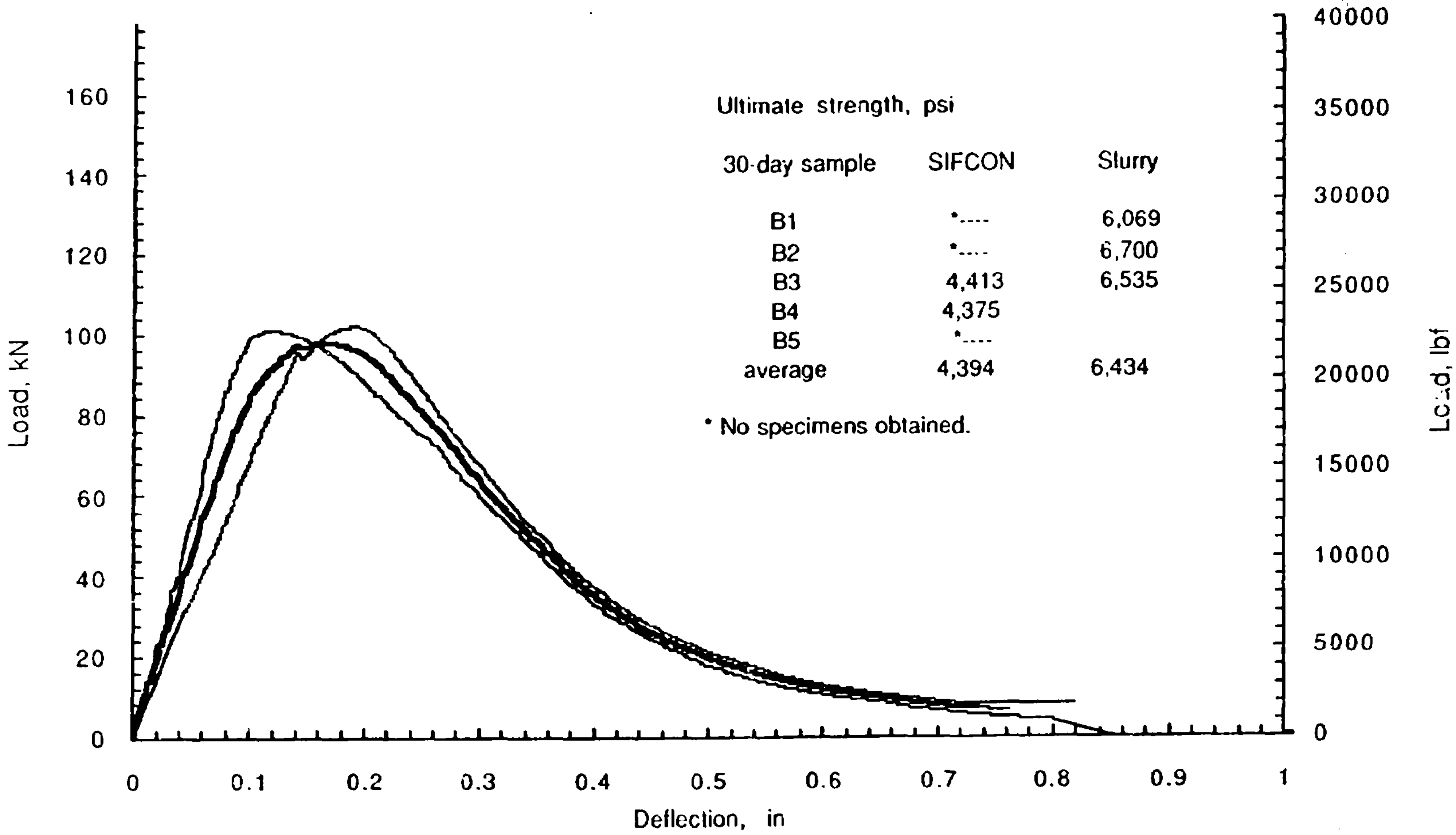


Figure C63. S 200-40-30 F flexure.

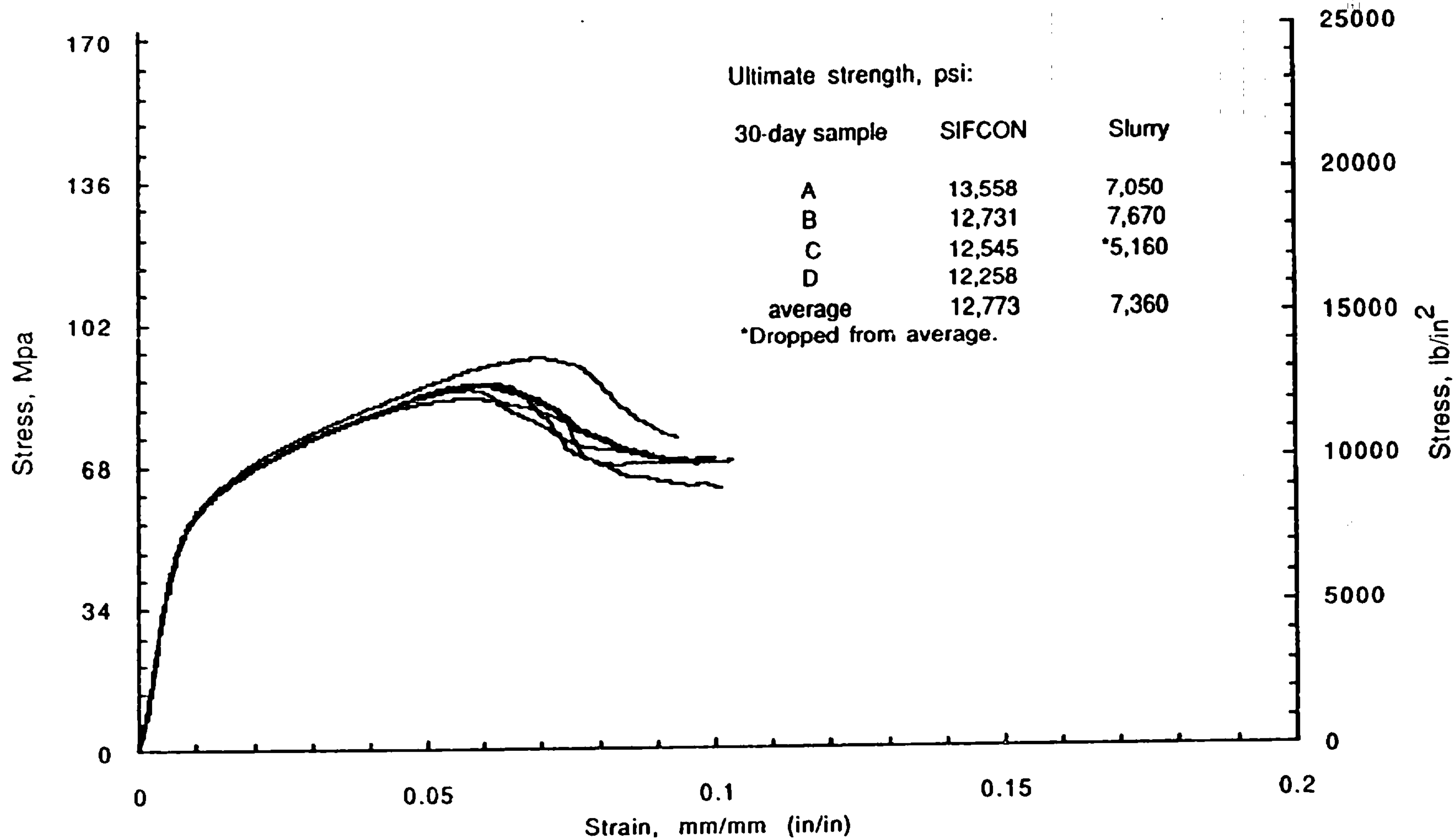


Figure C64. FAC 35-30 C compression.

FAC 35-30 C flexure does not exist since no specimens were molded and no specimens were tested.

Figure C65. FAC 35-30 C flexure.

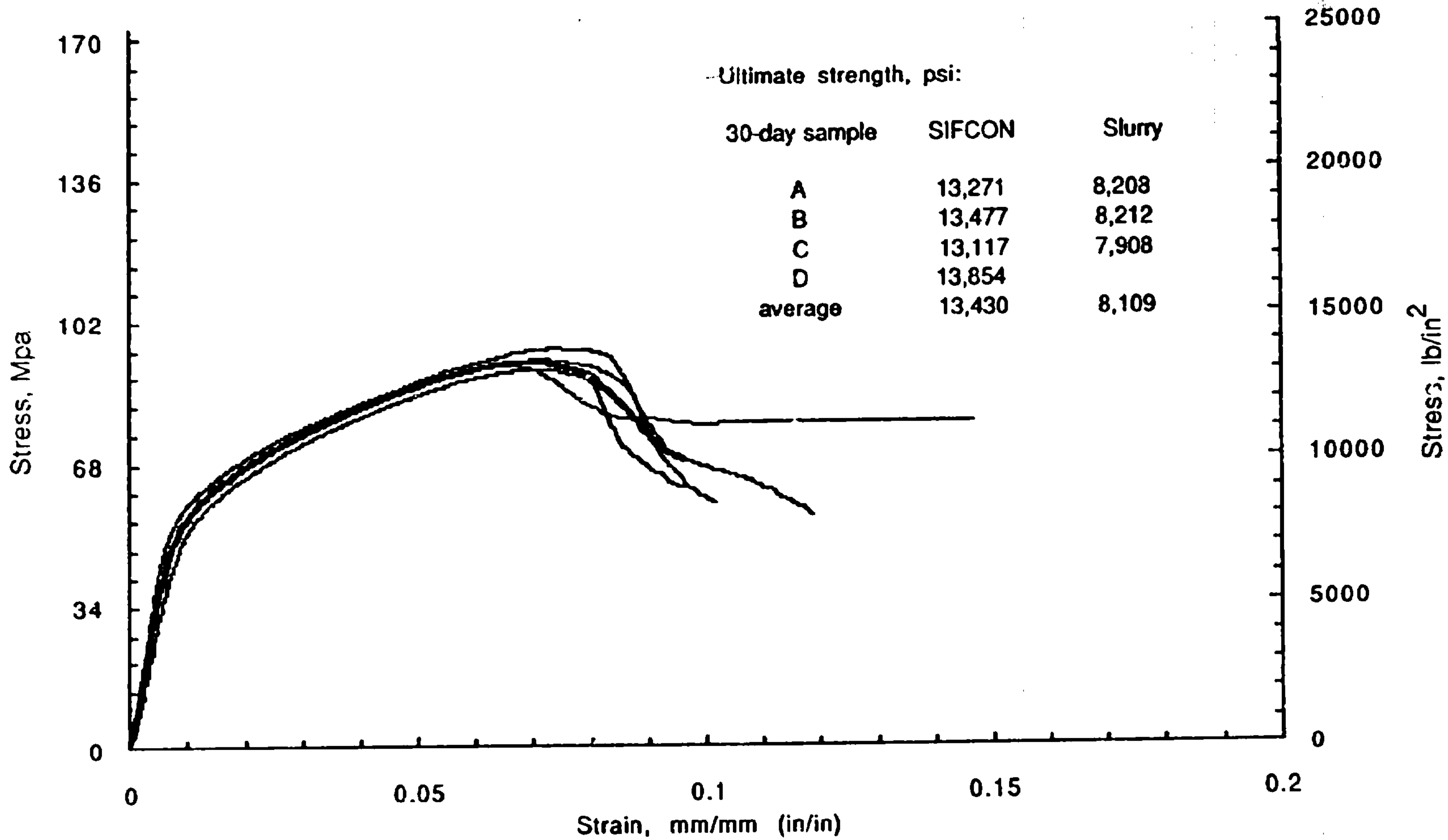


Figure C66. FAC 35-30 F compression.

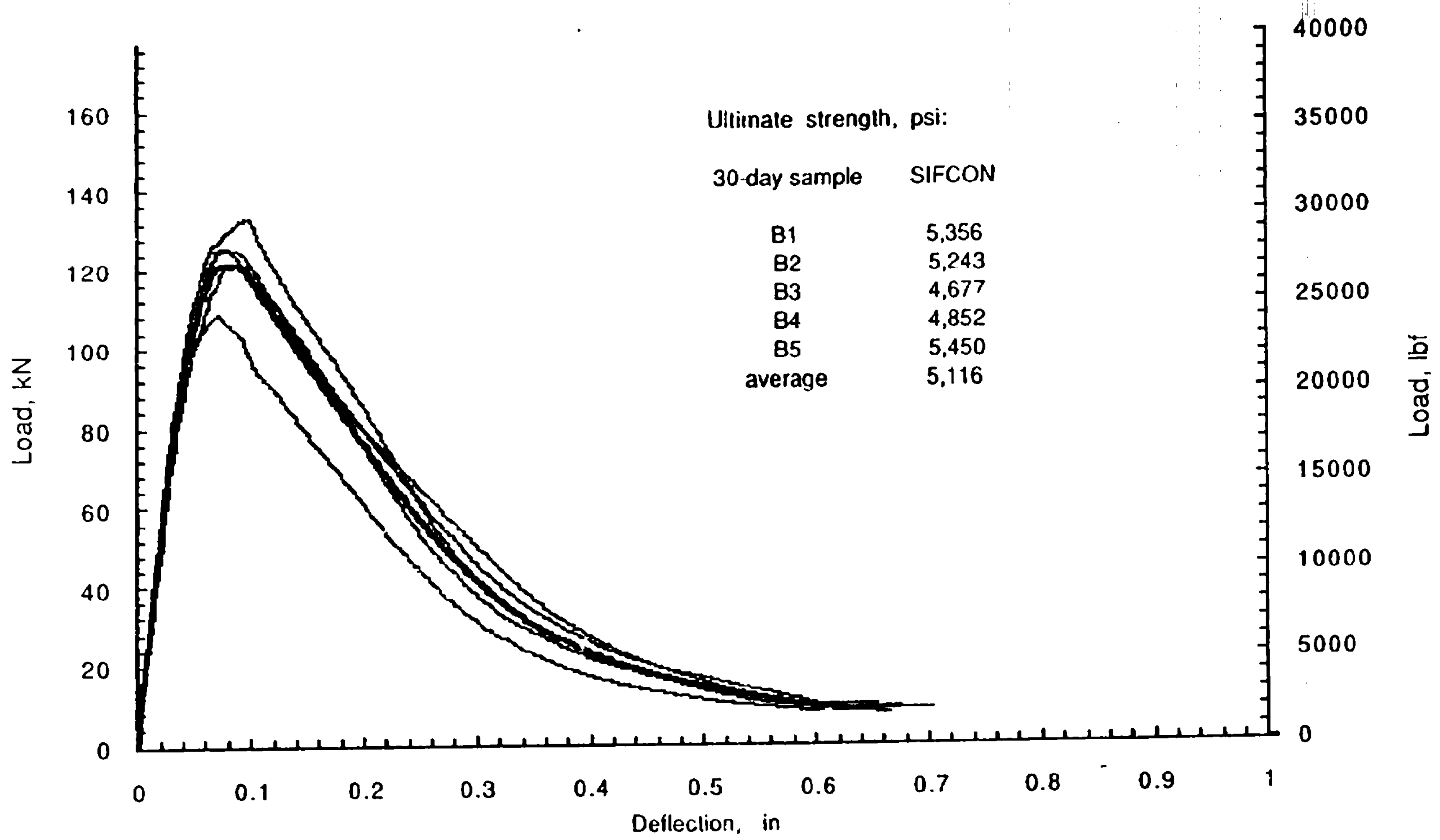


Figure C67. FAC 35-30 F flexure.

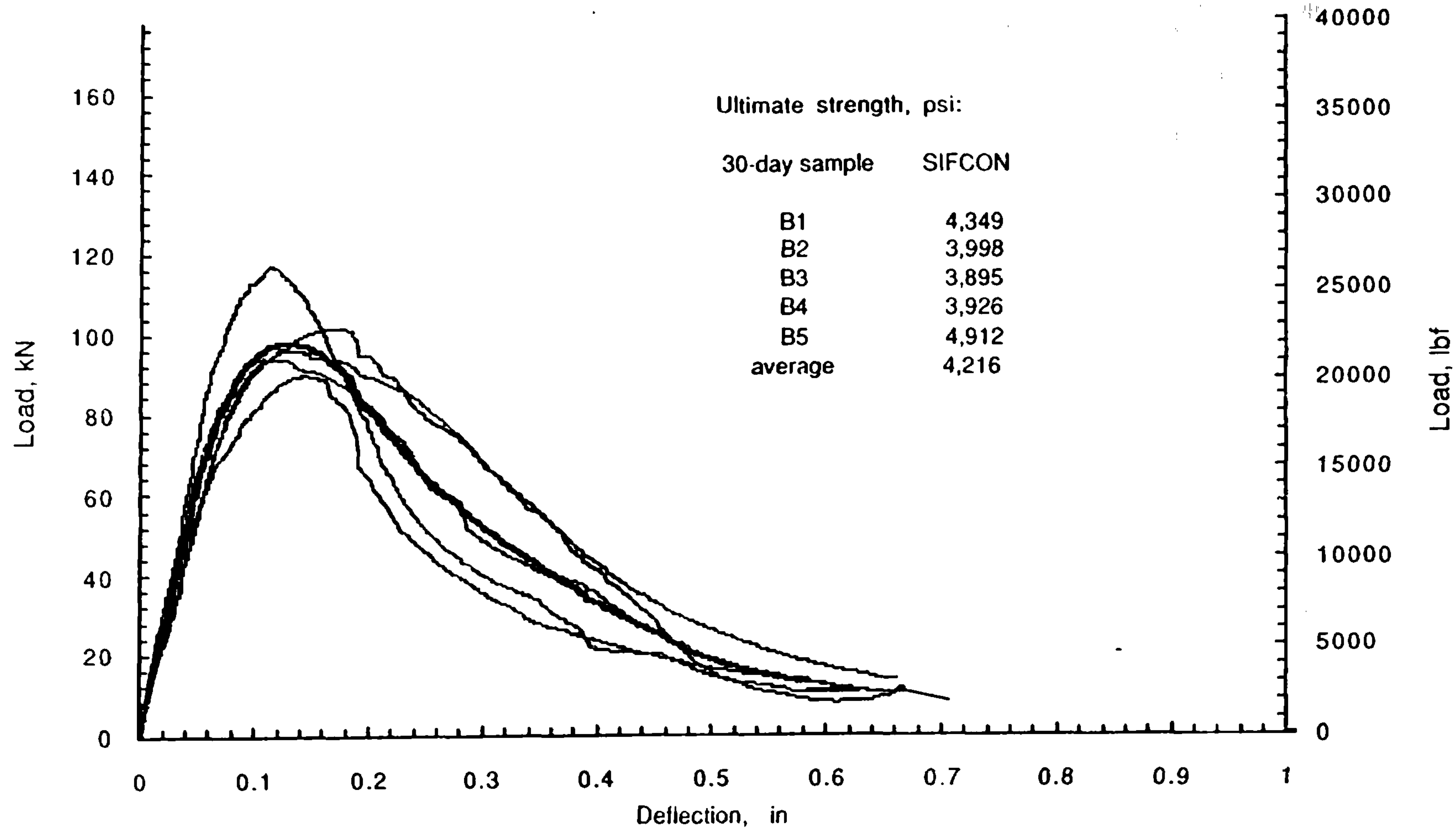


Figure C68. C 3-35-30 F flexure.

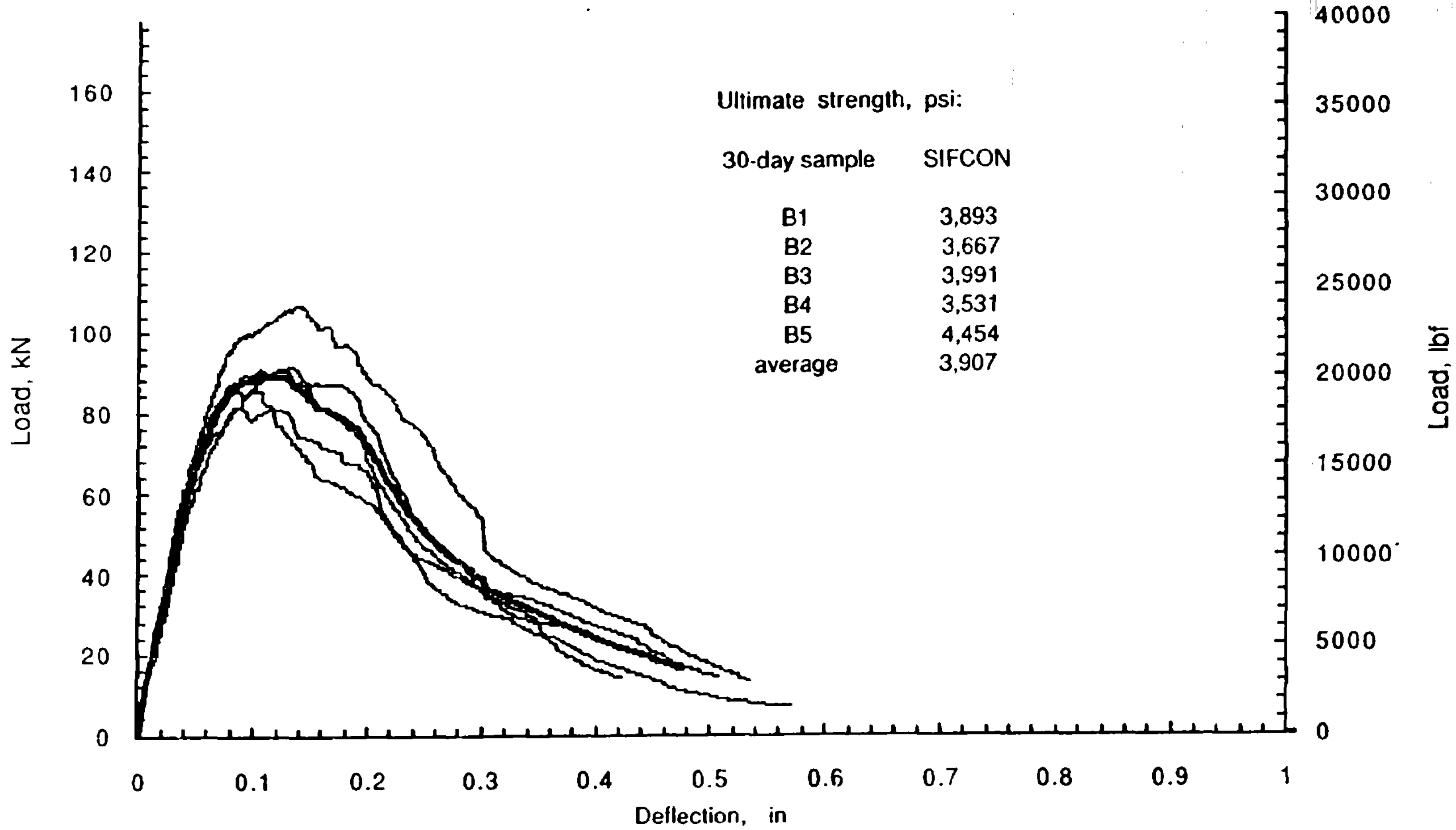


Figure C69. C 2-35-30 F flexure.

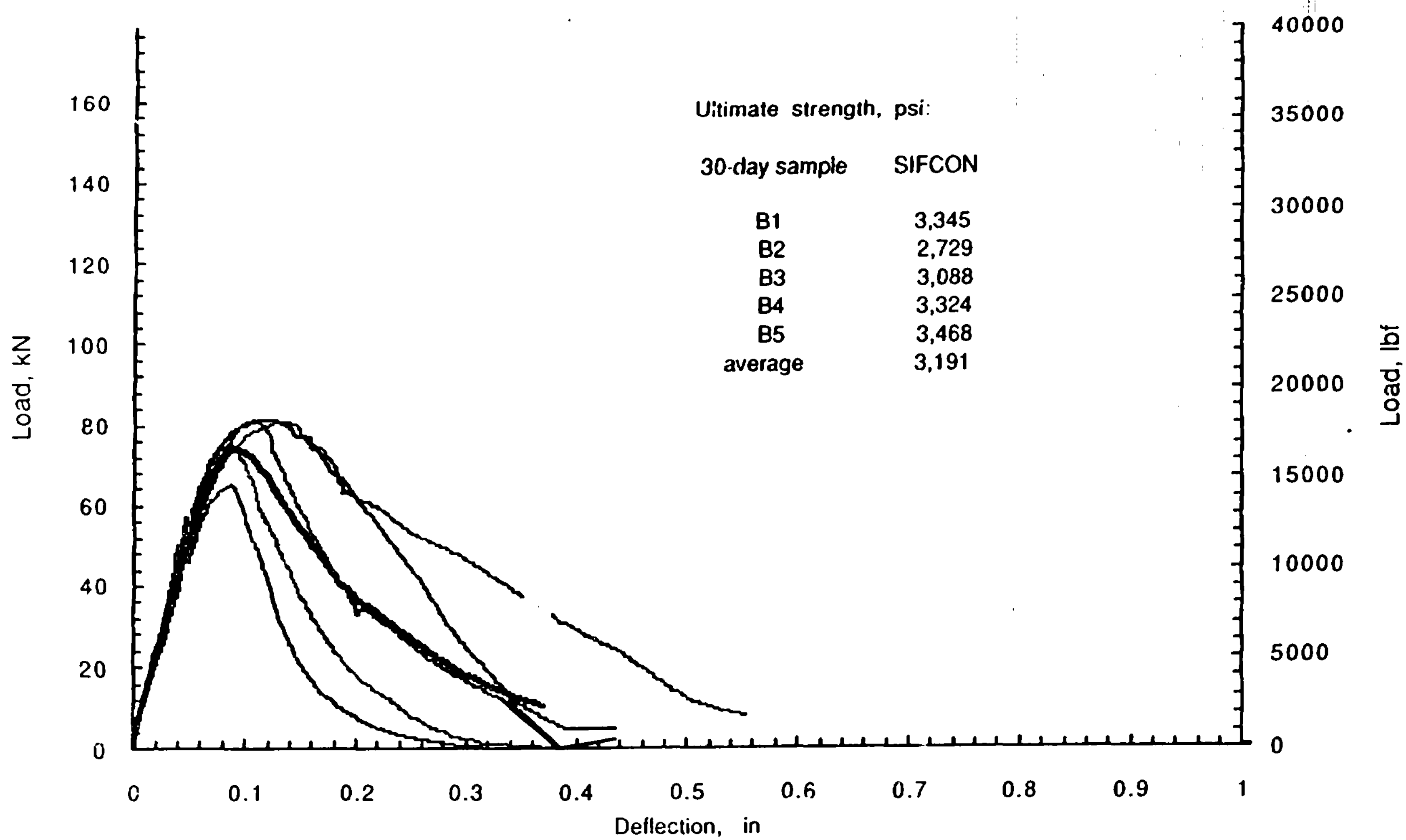


Figure C70. C 1.5-35-30 F flexure.

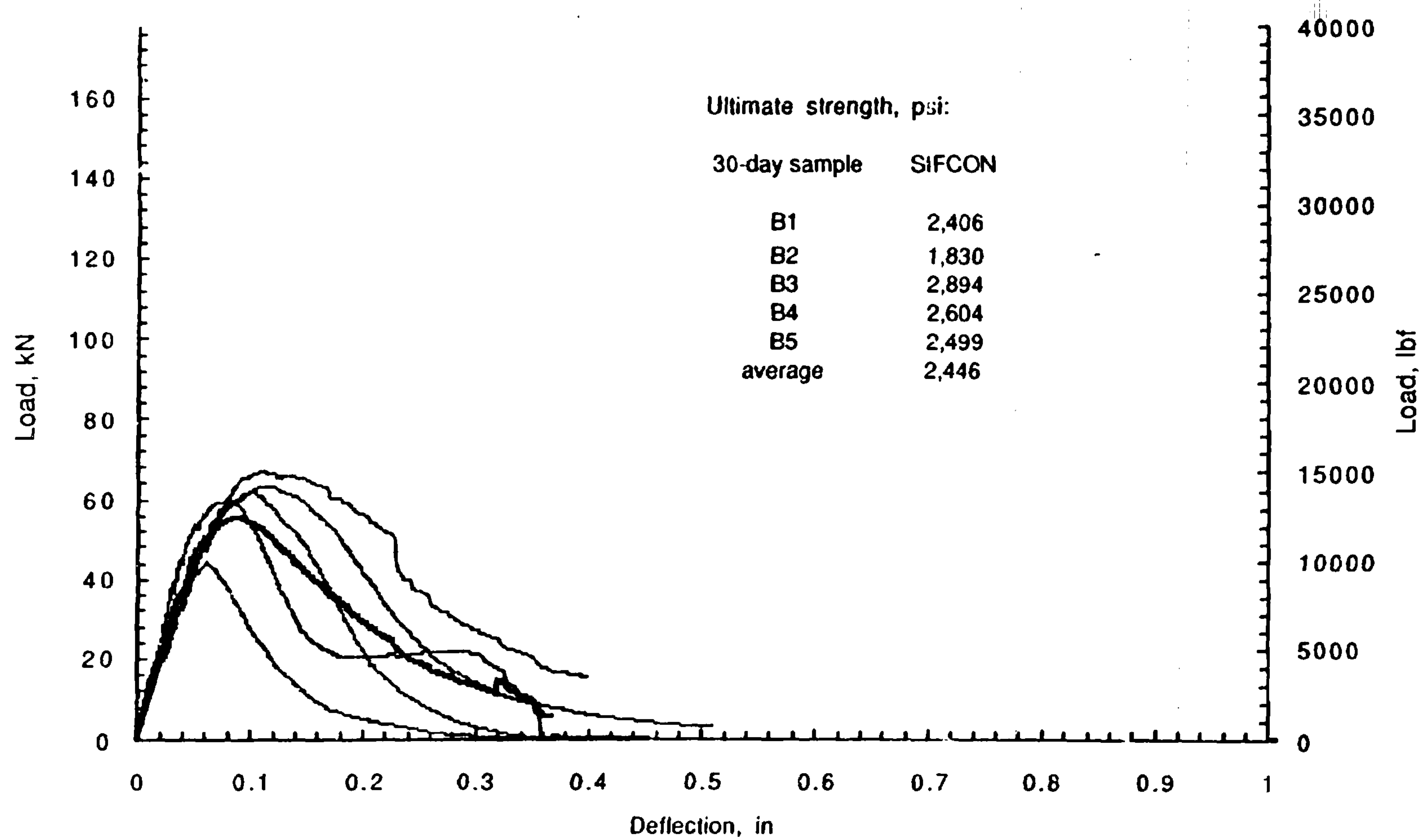


Figure C71. C 1-35-30 F flexure.

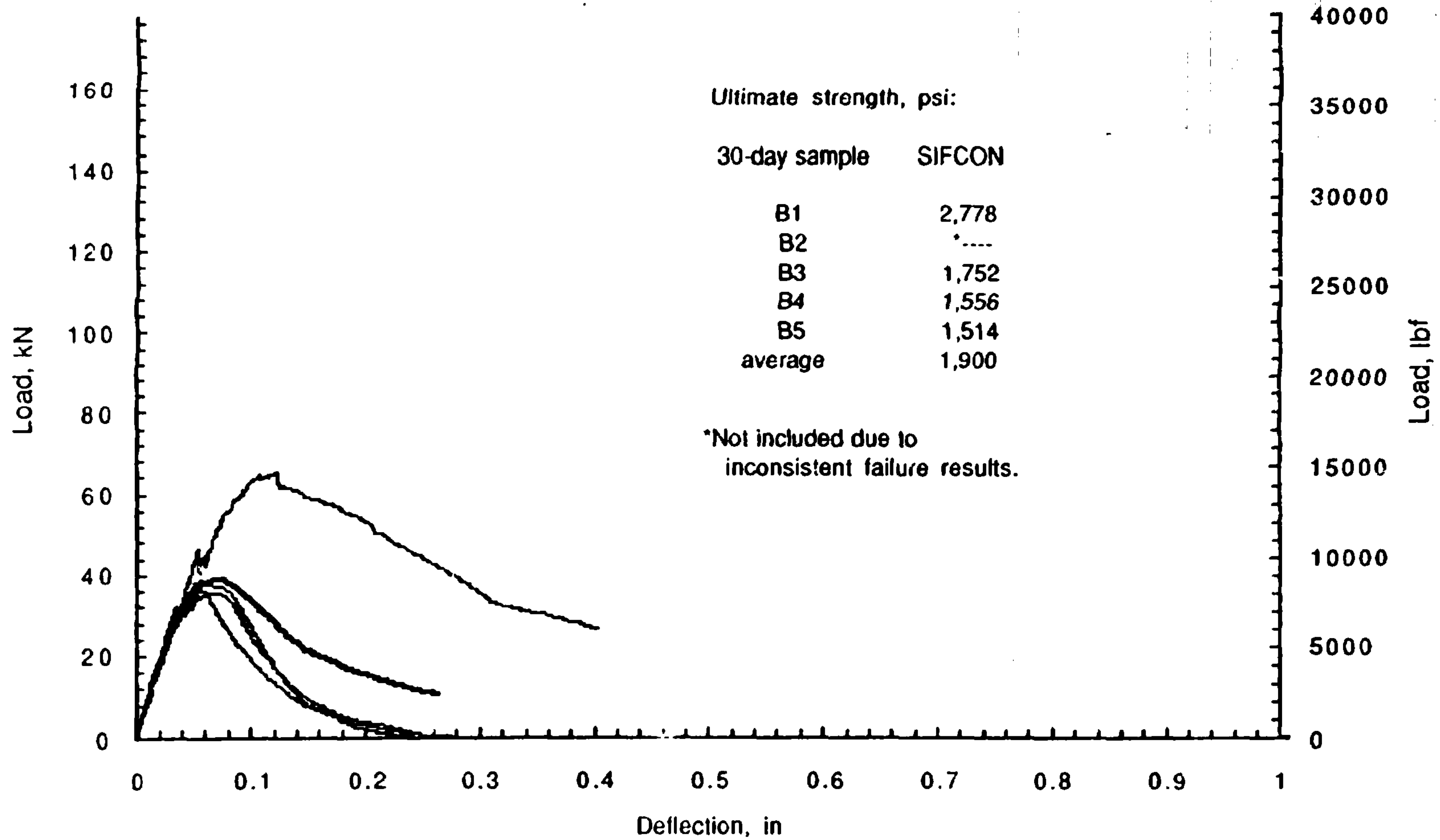


Figure C72. C 0.5-35-30 F flexure.

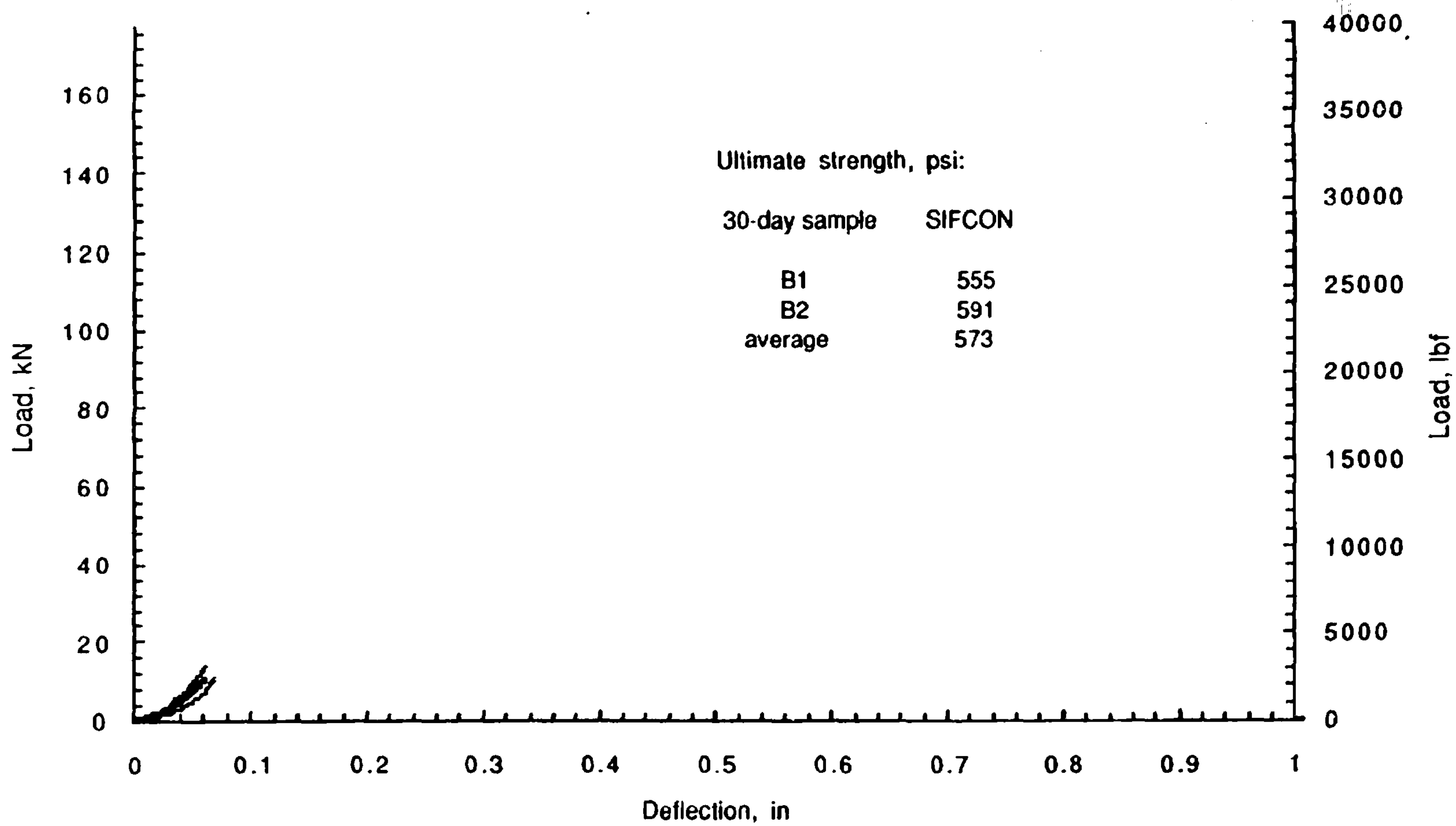


Figure C73. C 0-35-30 C flexure.

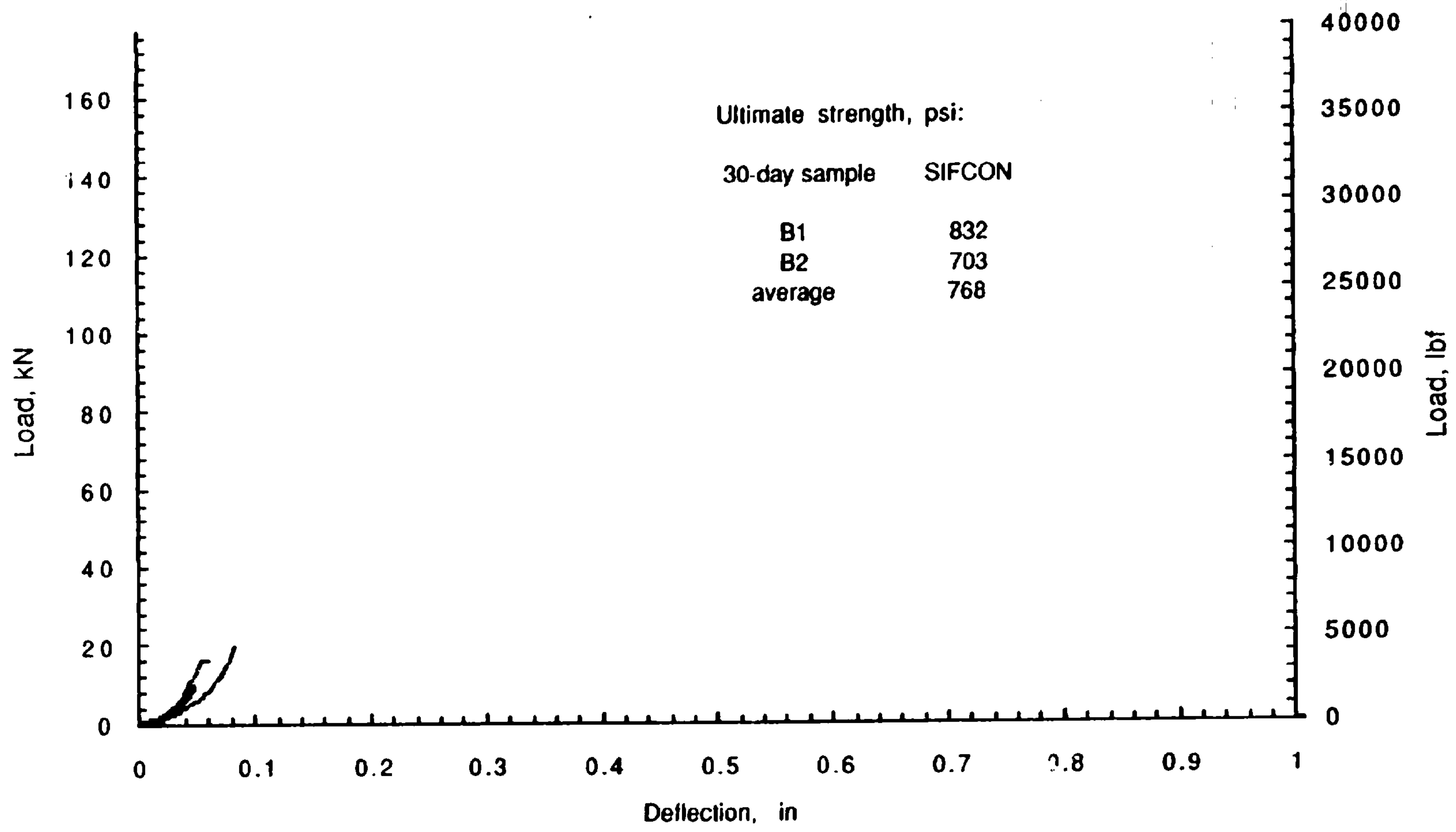


Figure C74. C 0-35-30 F flexure.

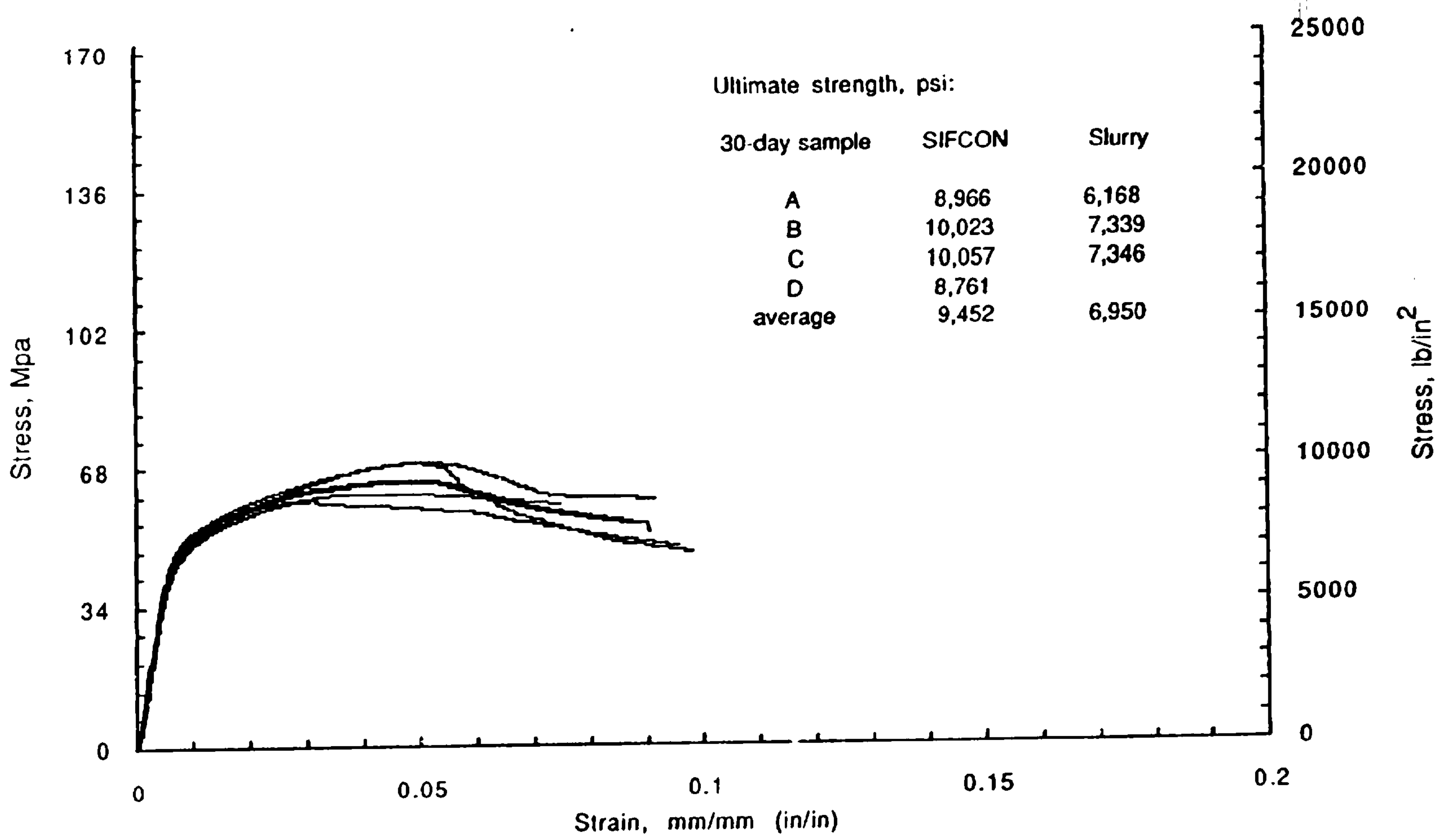


Figure C75. FAC 35-30 D compression.

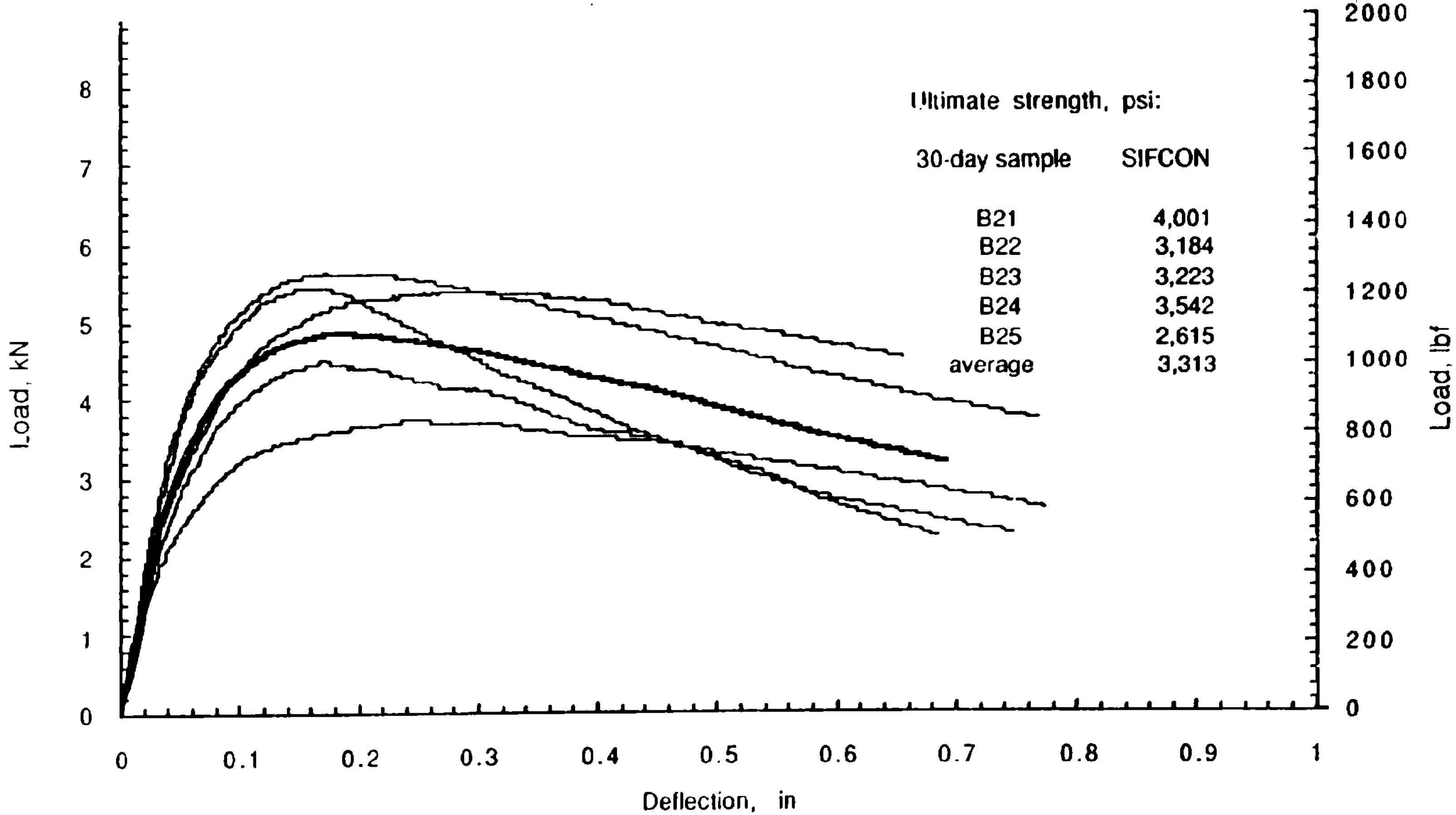


Figure C76. FAC 35-30 D (1-in depth) flexure.

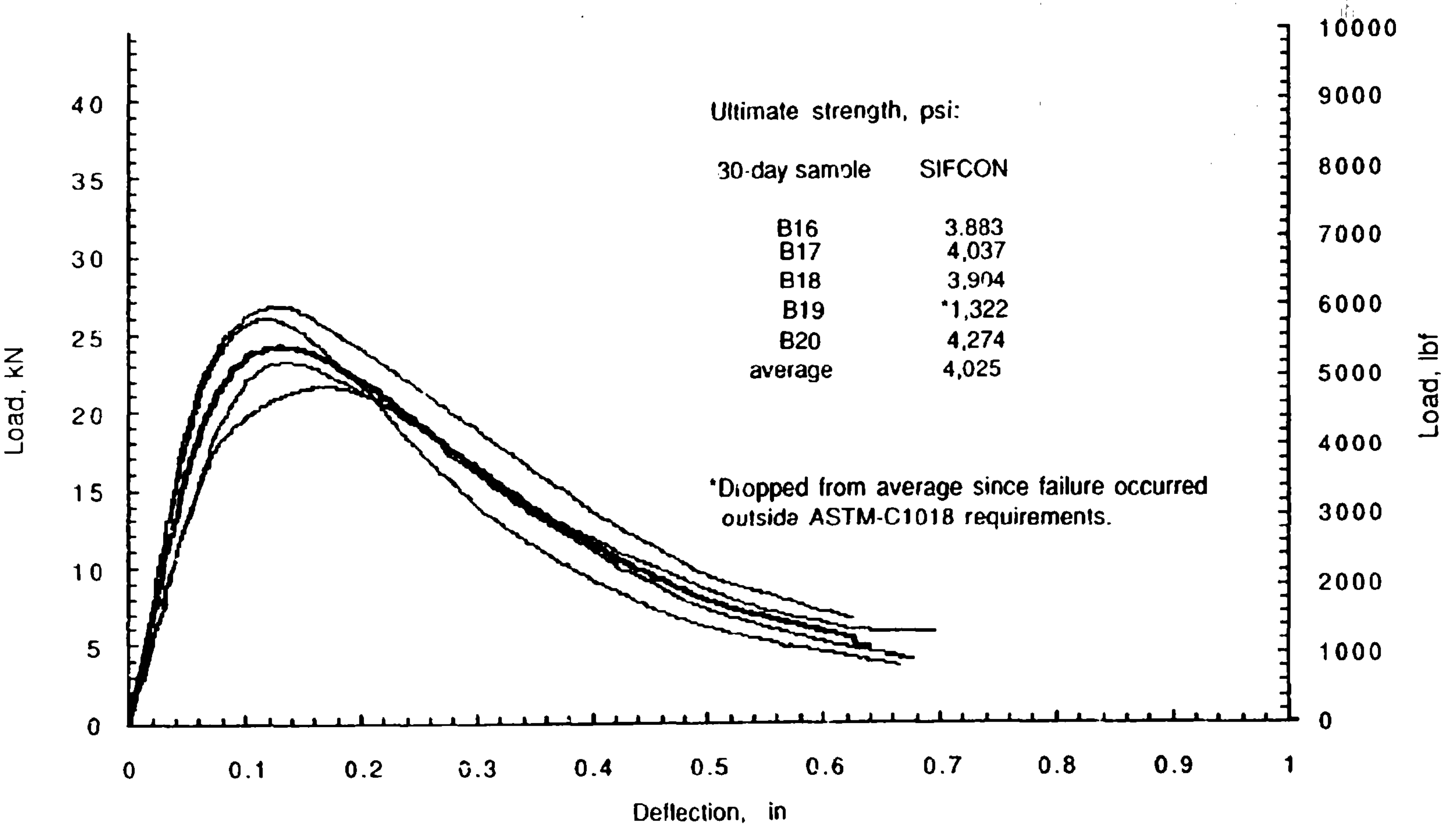


Figure C77. FAC 35-30 D (2-in depth) flexure.

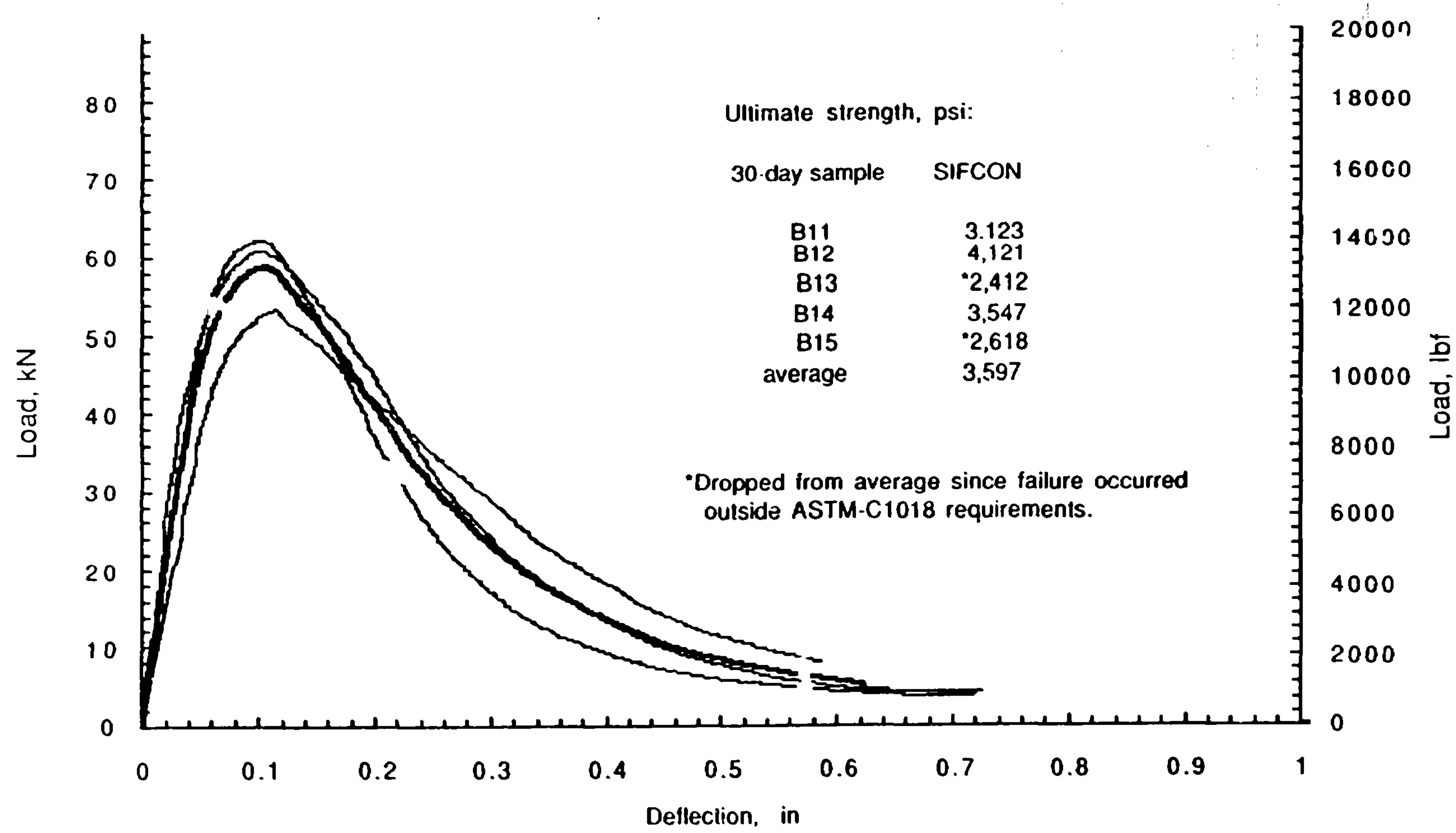


Figure C78. FAC 35-30 D (3-in depth) flexure.

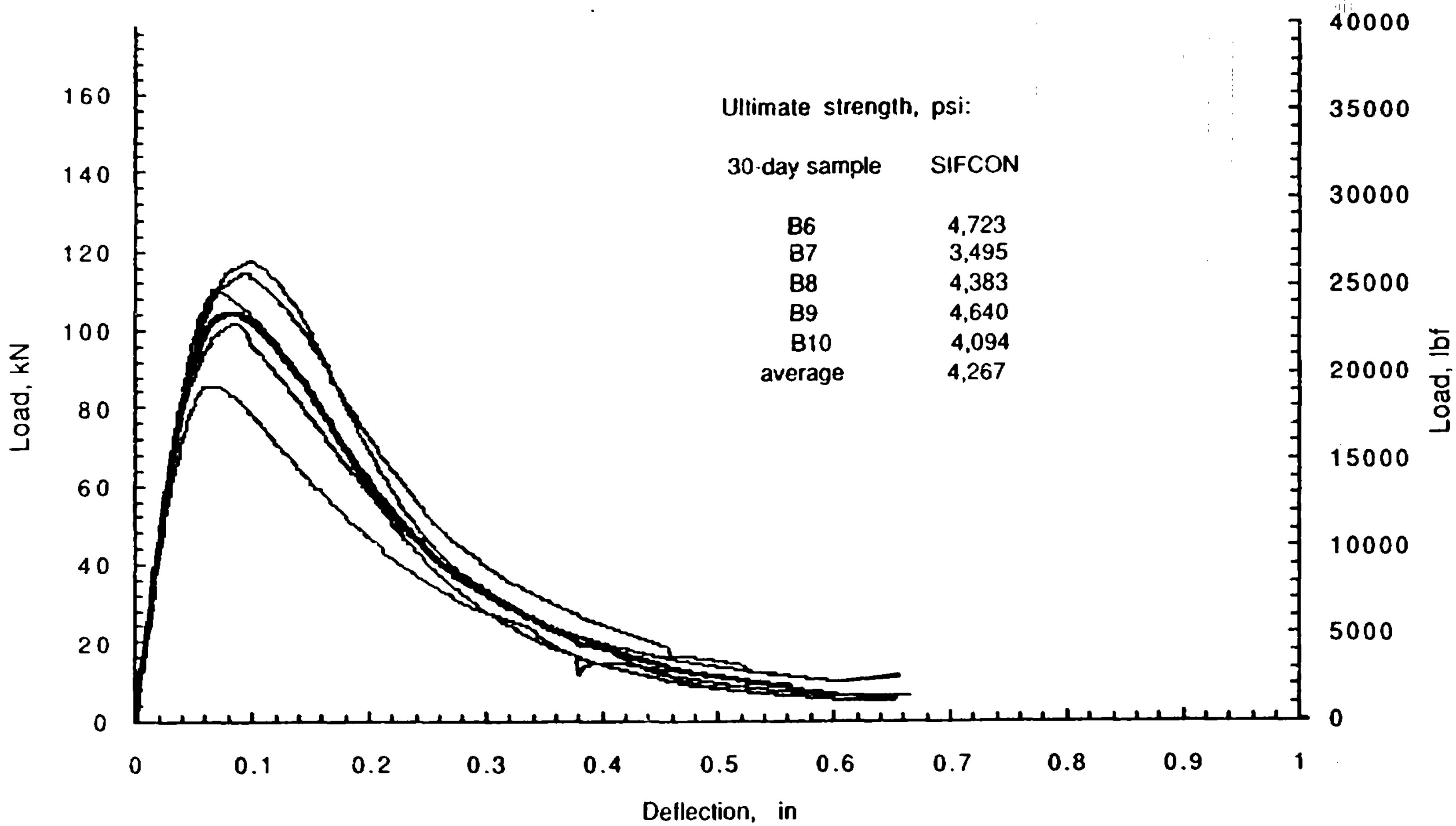


Figure C79. FAC 35-30 D (4-in depth) flexure.

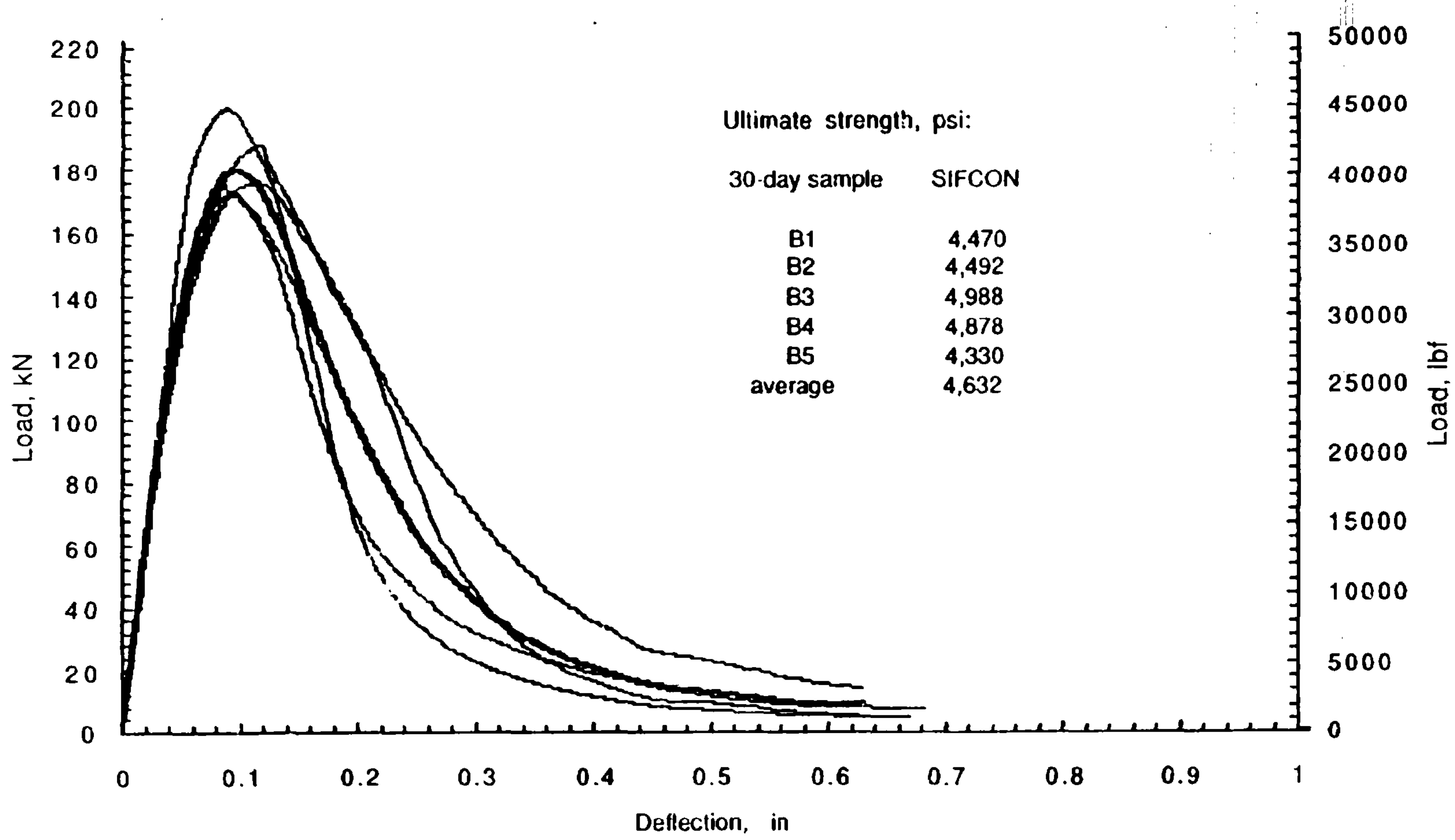


Figure C80. FAC 35-30 D (5-in depth) flexure.

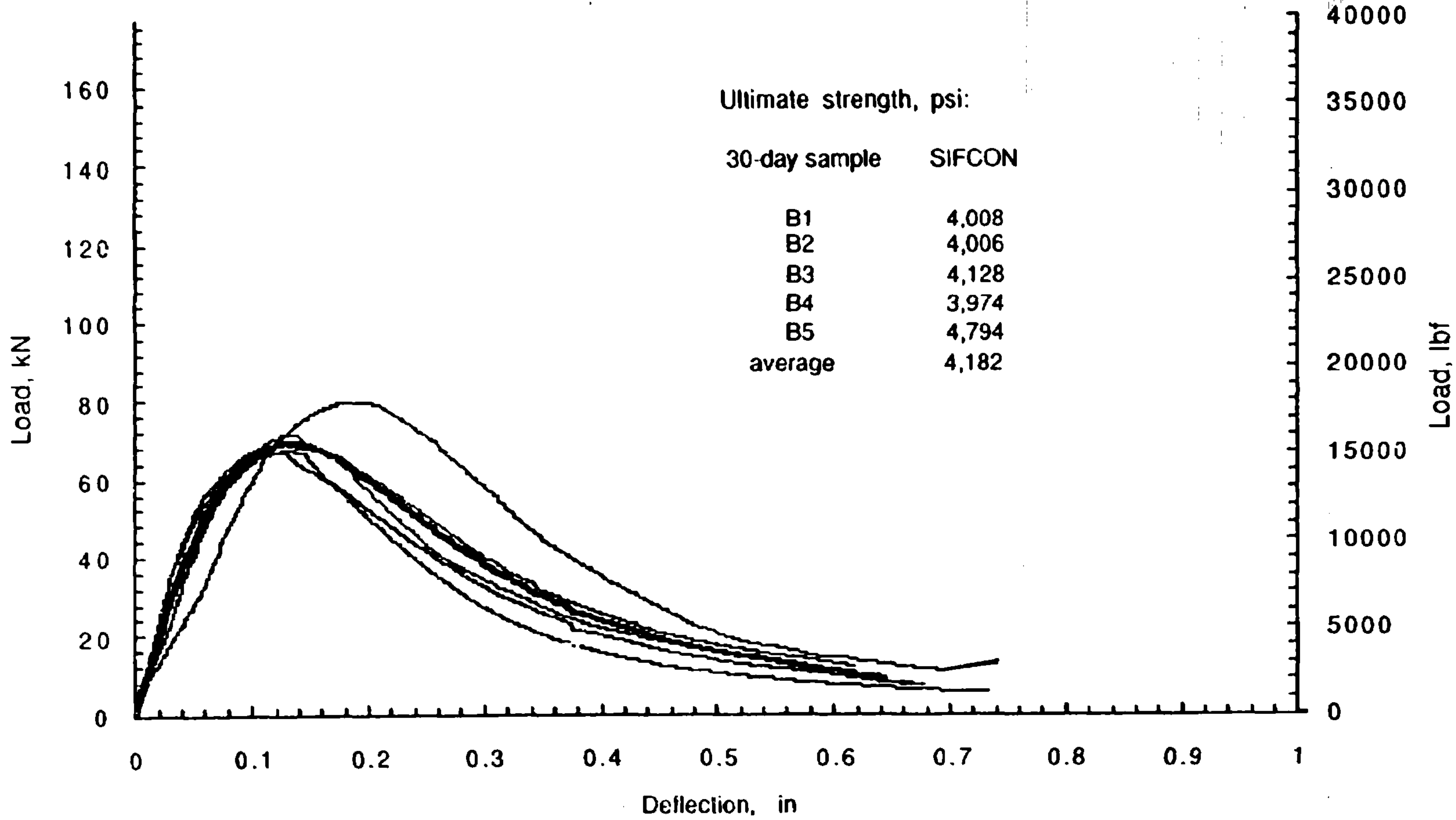


Figure C81. FAC 35-30 D (4-in long) flexure.

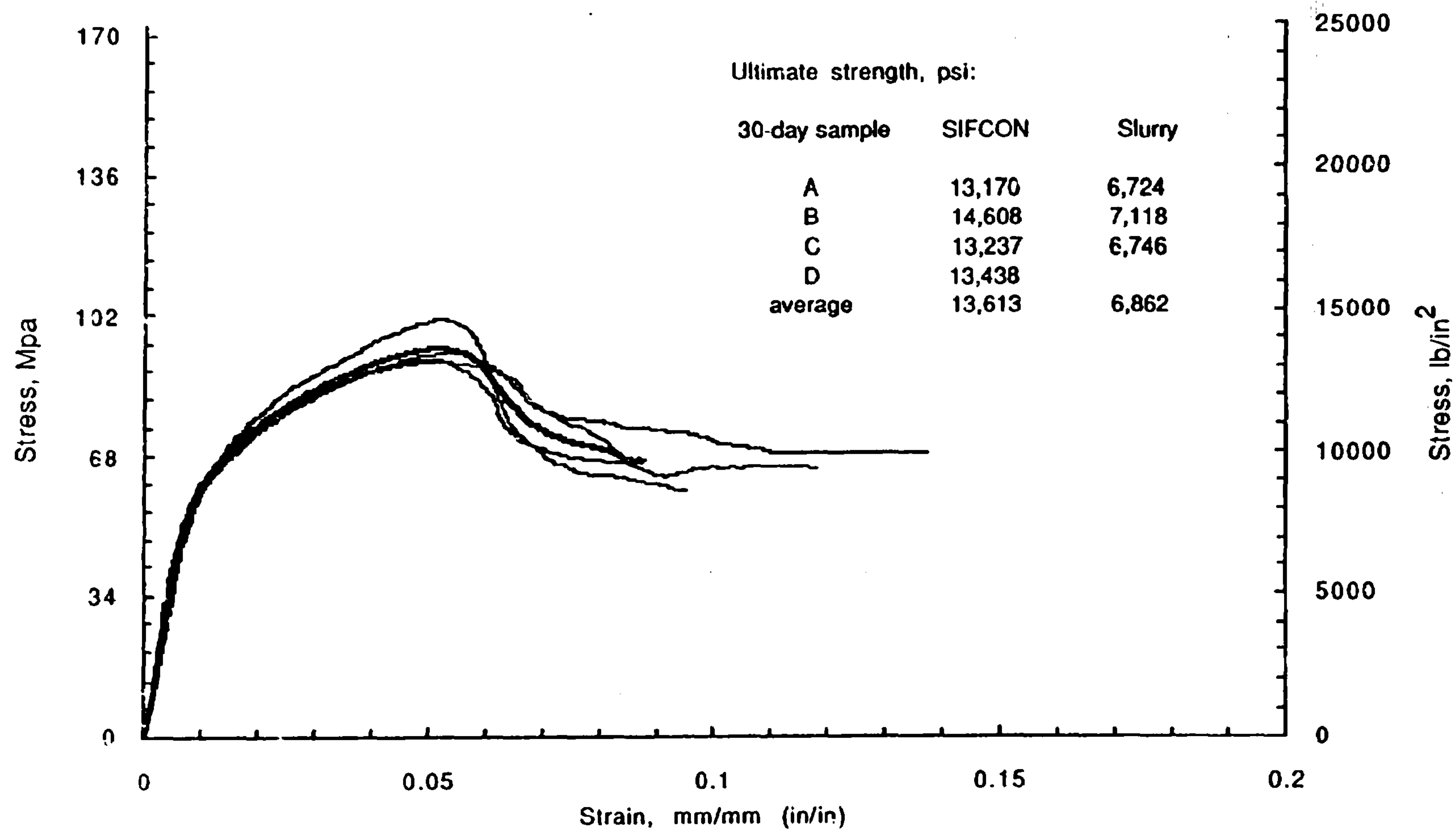


Figure C82. FAC 35-30 E (typical) compression.

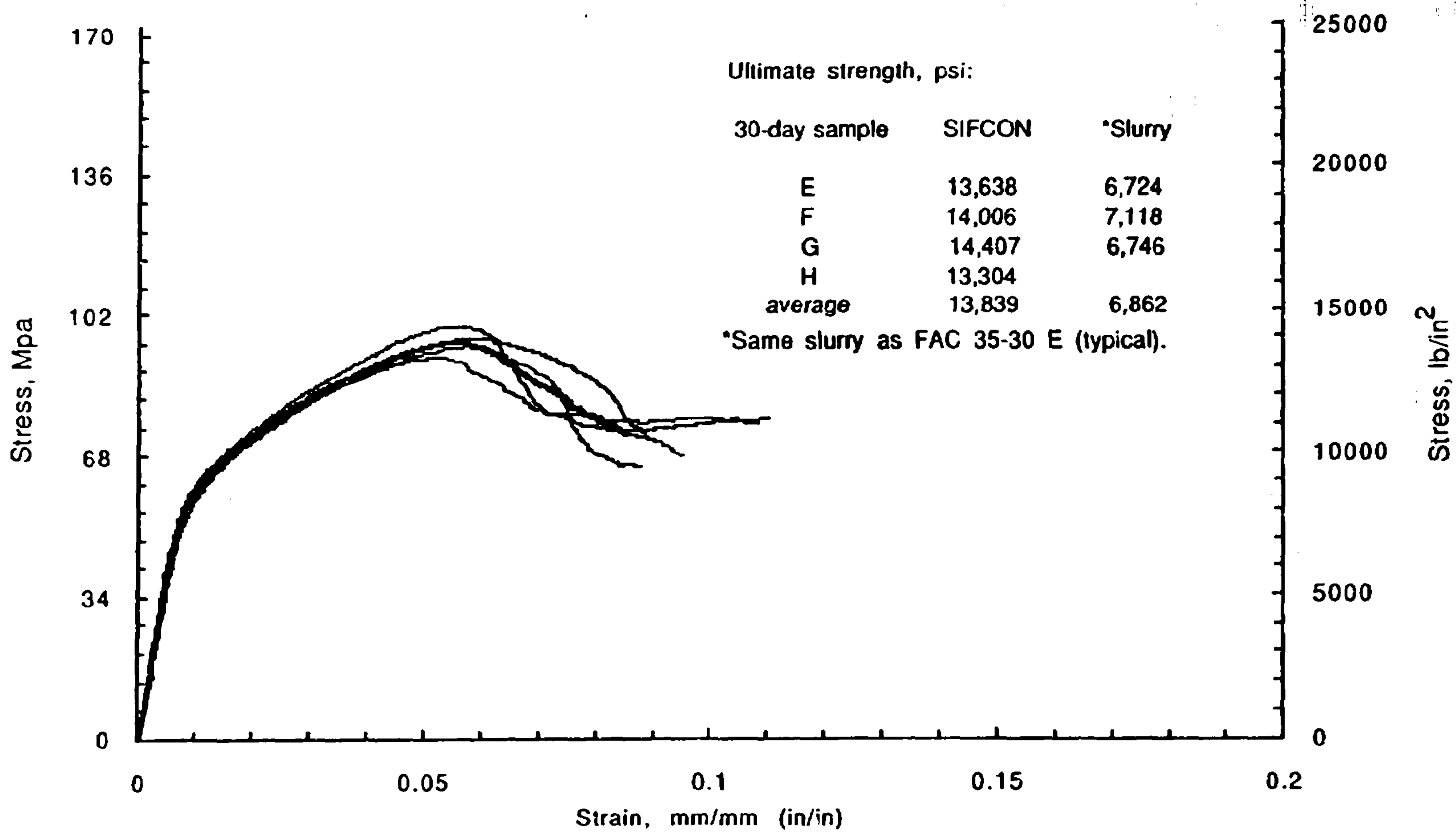


Figure C83. FAC 35-30 E (control) compression.

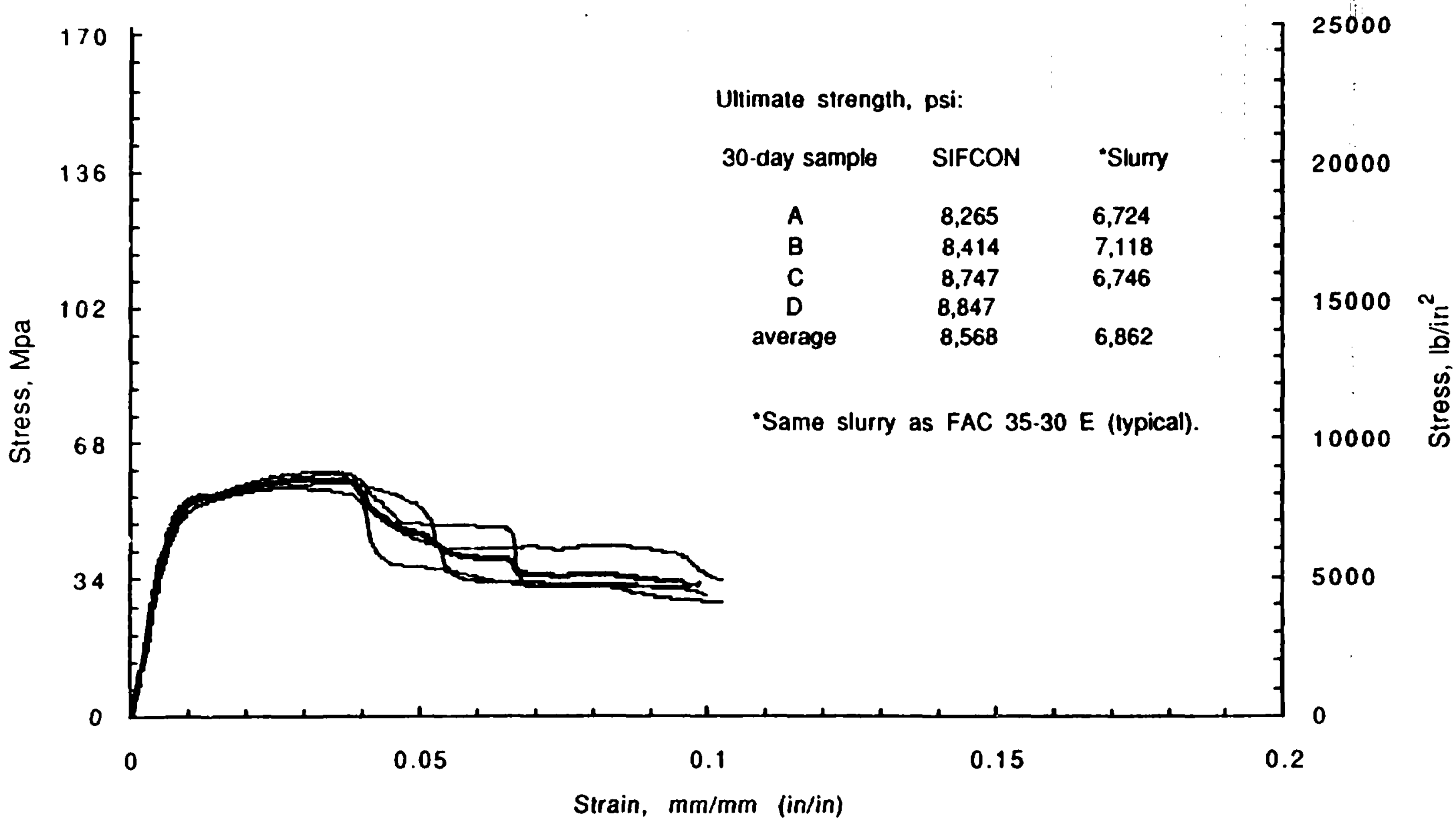


Figure C84. Z 5/5-35-30 E (typical) compression.

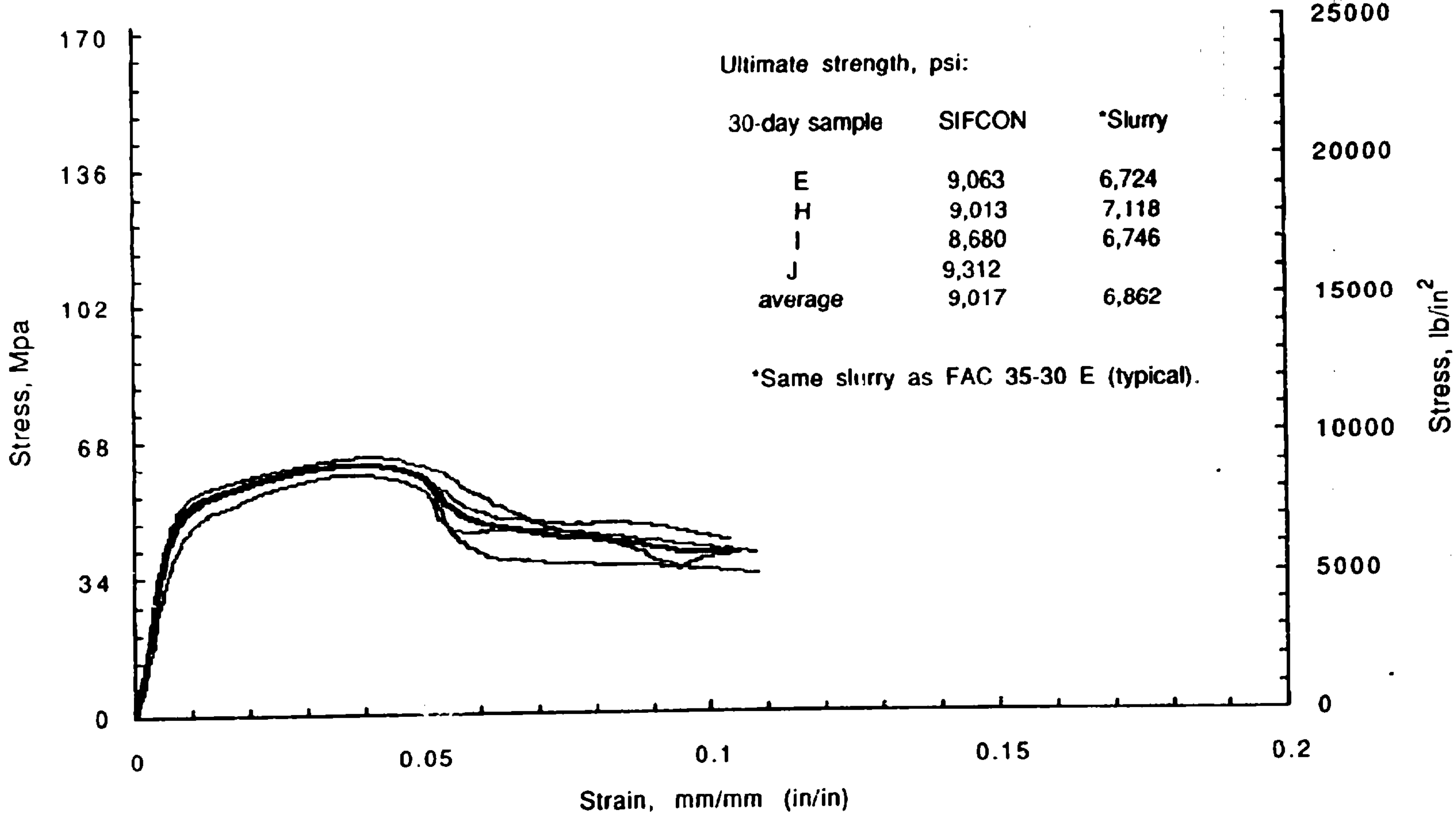


Figure C85. Z 5/5-35-35-30 E (control) compression.

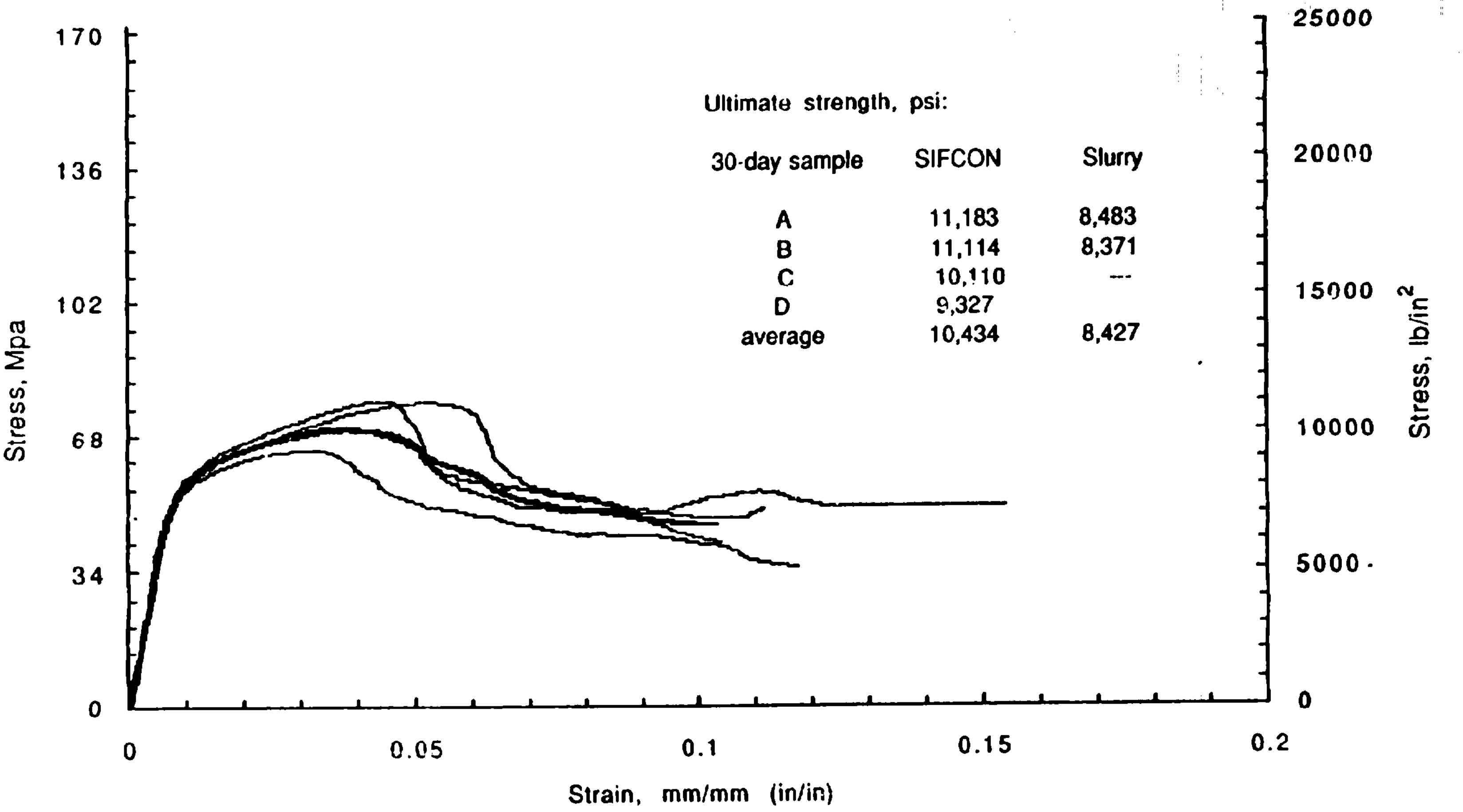


Figure C86. FAC 35-30 S compression.

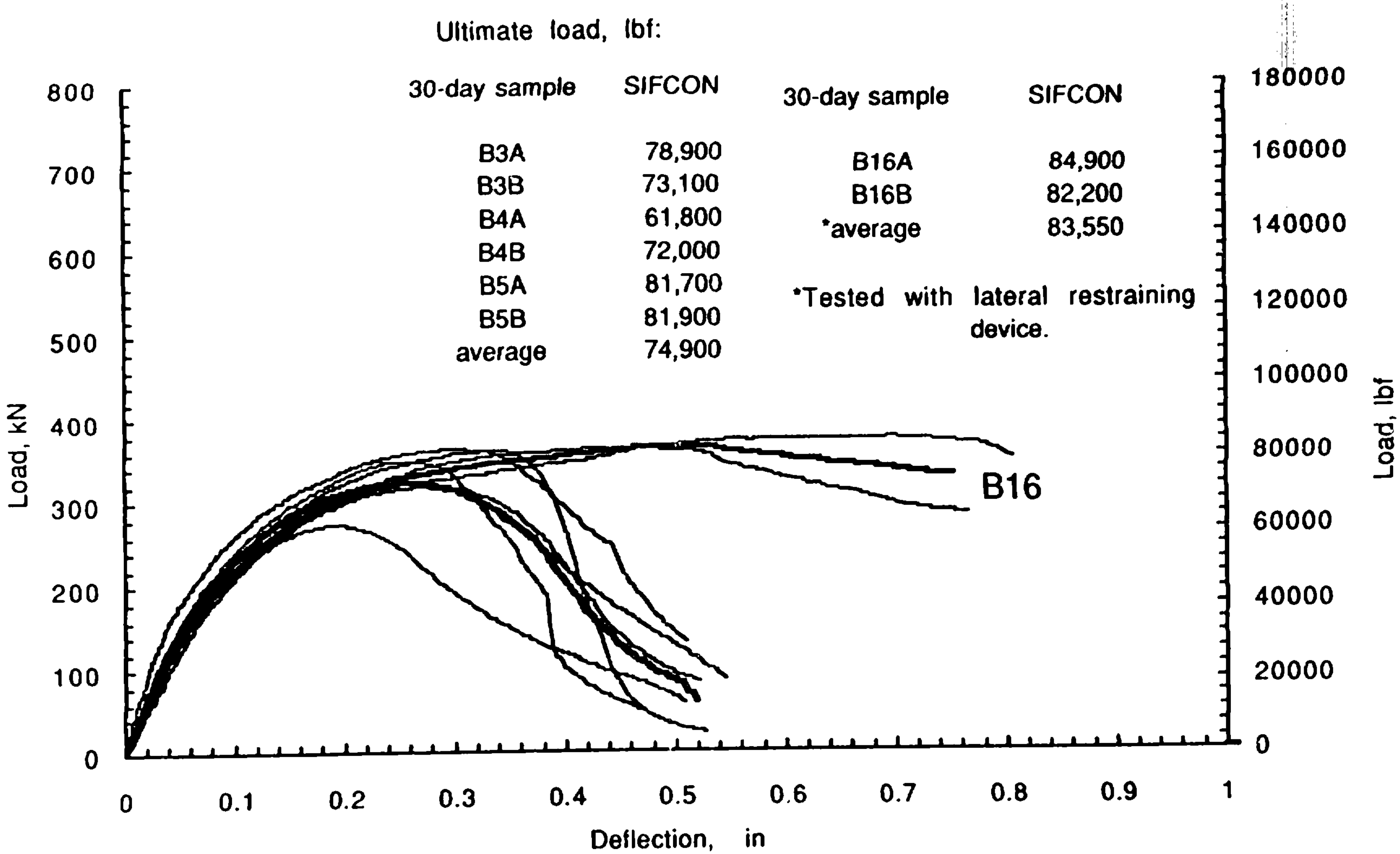


Figure C87. FAC 35-30 S (5-in) shear.

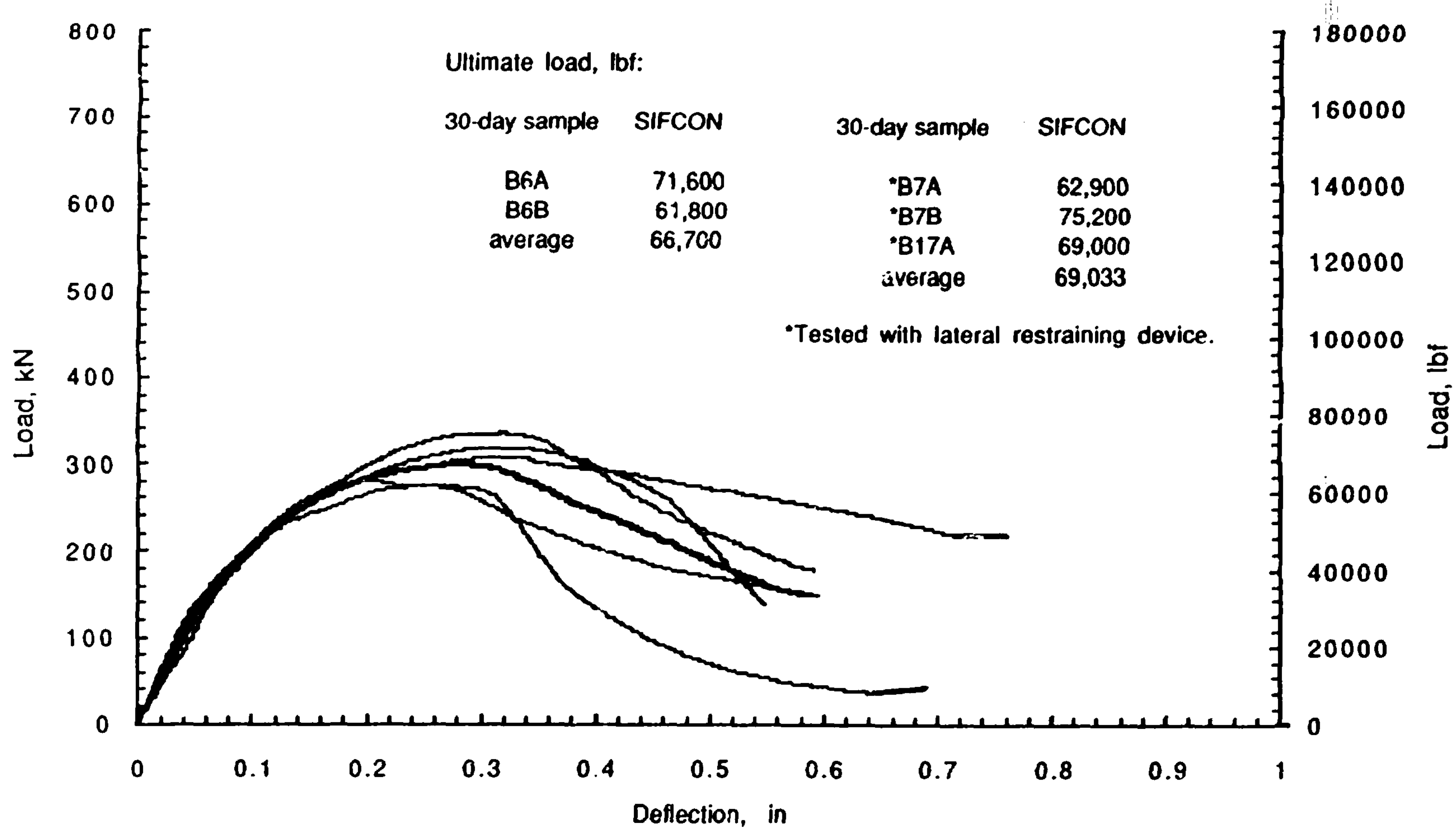


Figure C88. FAC 35-30 S (6-in) shear.

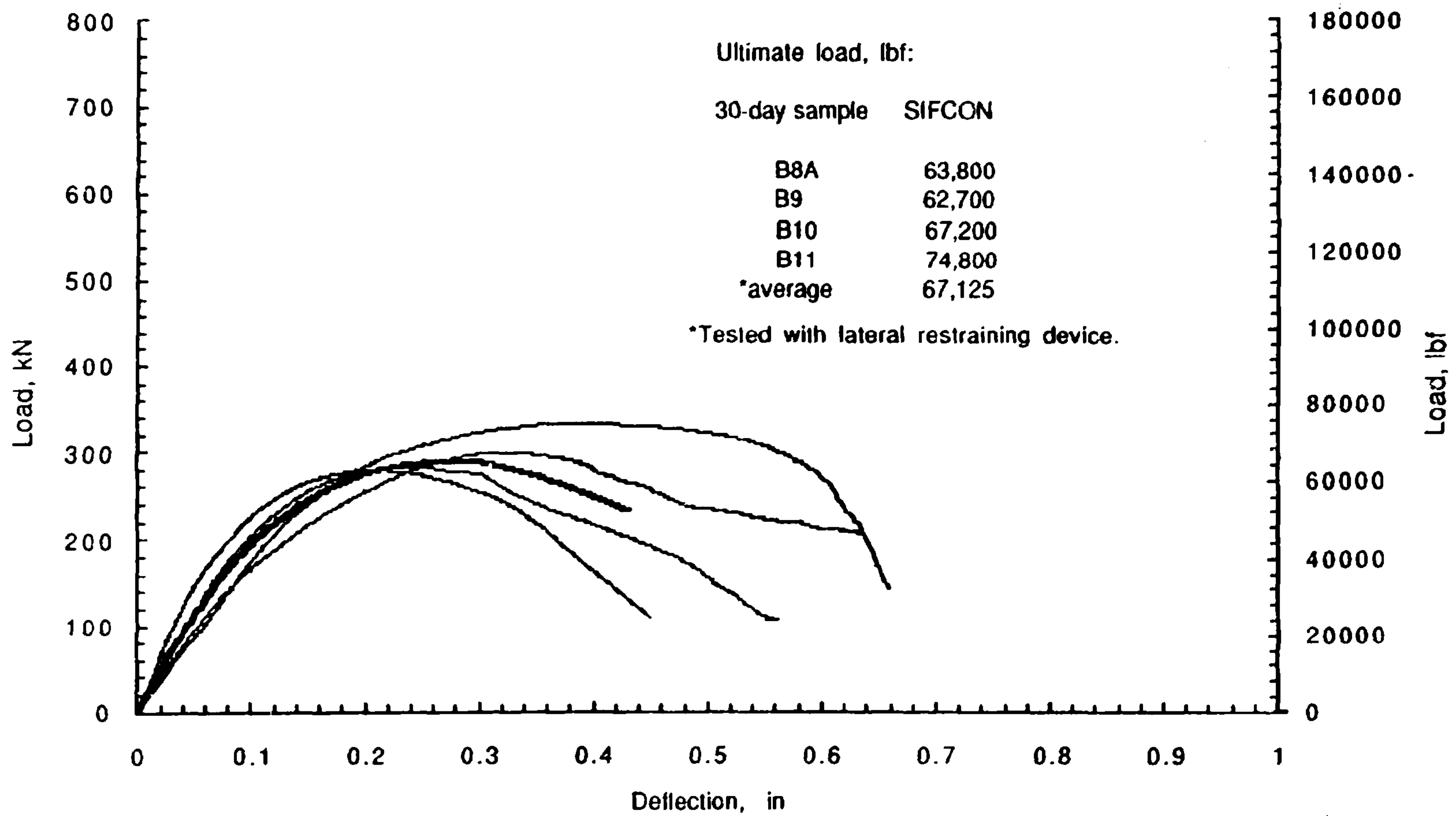


Figure C89. FAC 35-30 S (7-in) shear.

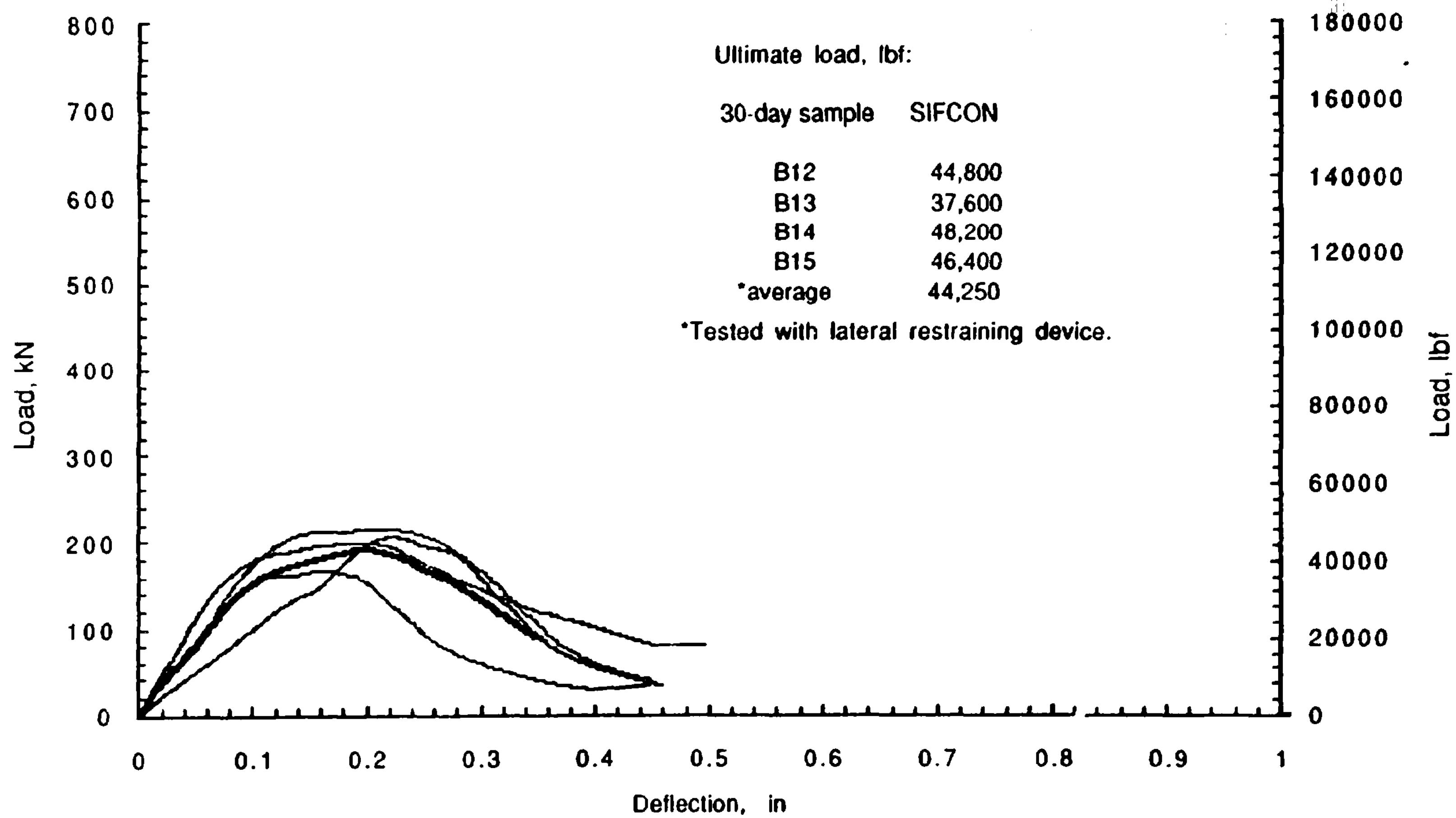


Figure C90. FAC 35-30 S (8-in) shear.

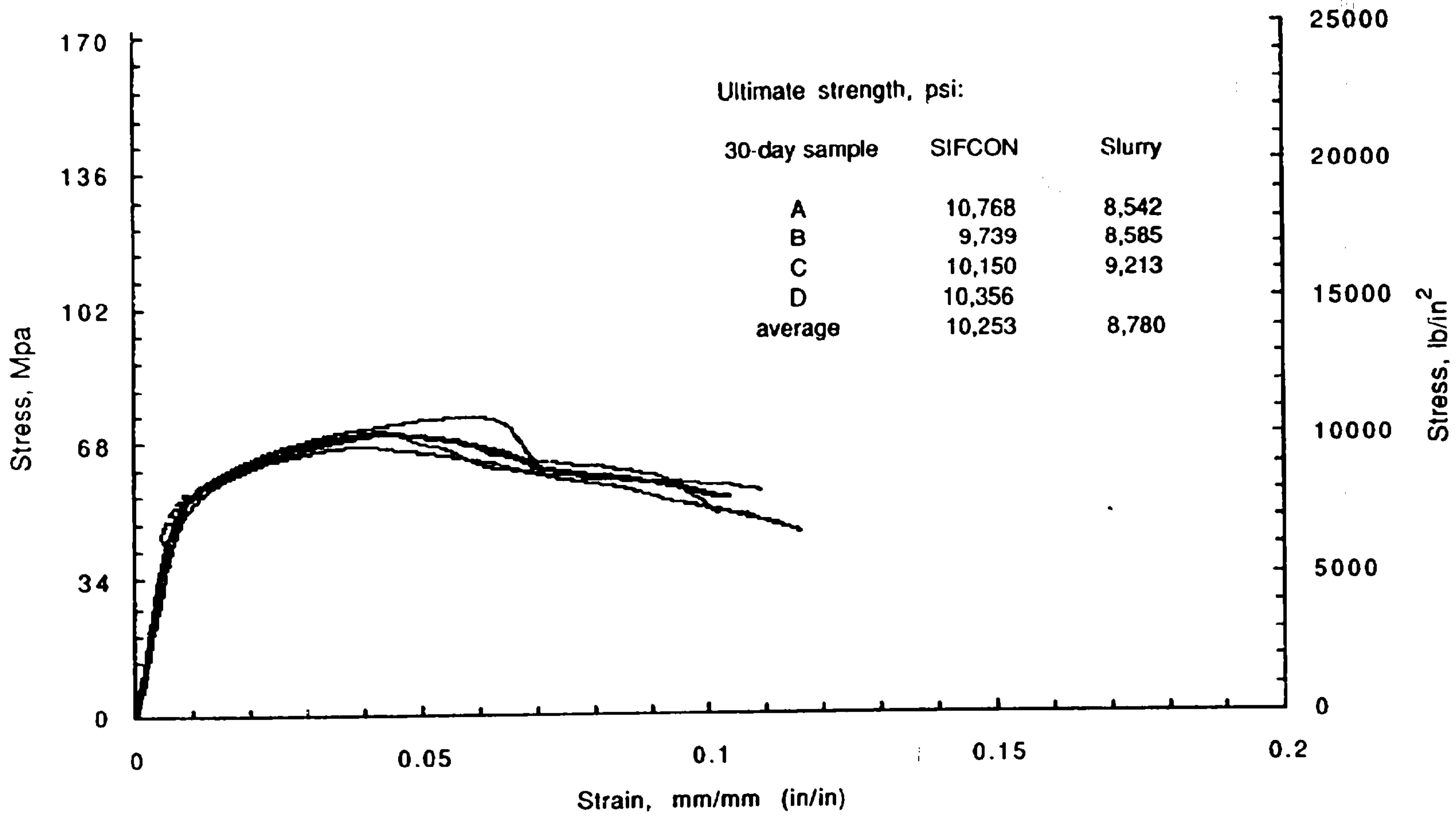


Figure C91. FAC 35-30 T compression.

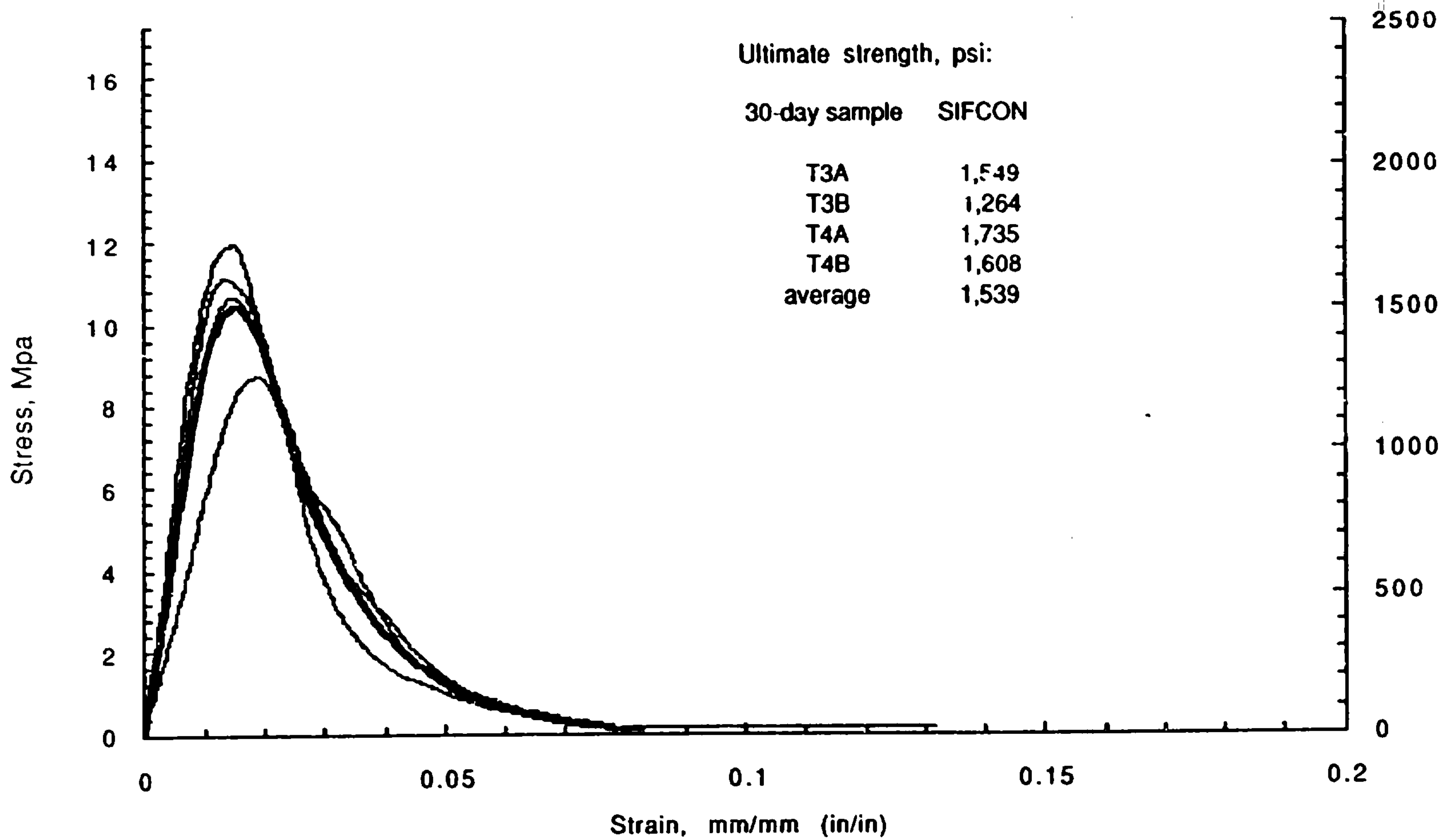


Figure C92. FAC 35-30 T (0.5-in) tension.

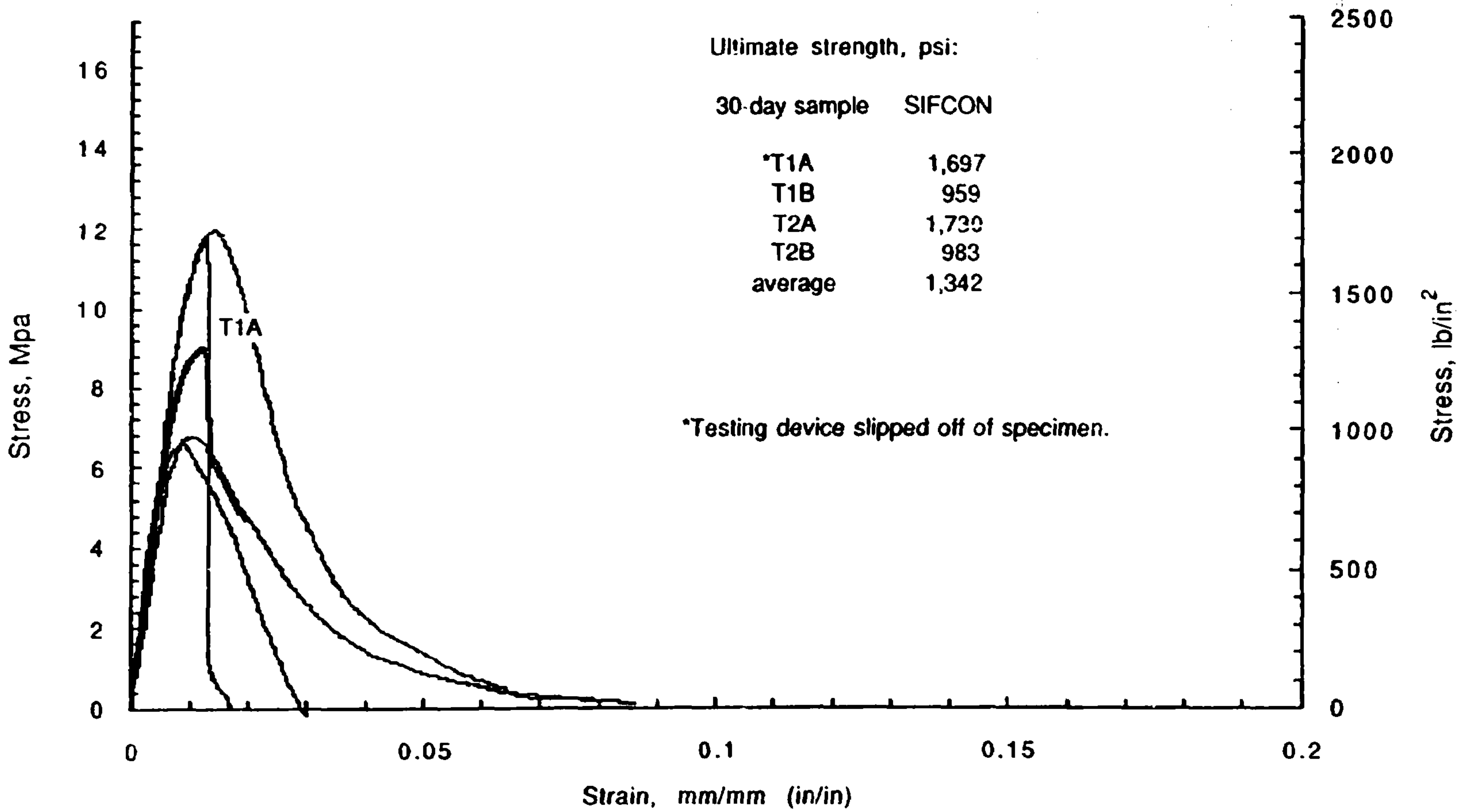


Figure C93. FAC 35-30 T (0.75-in) tension.

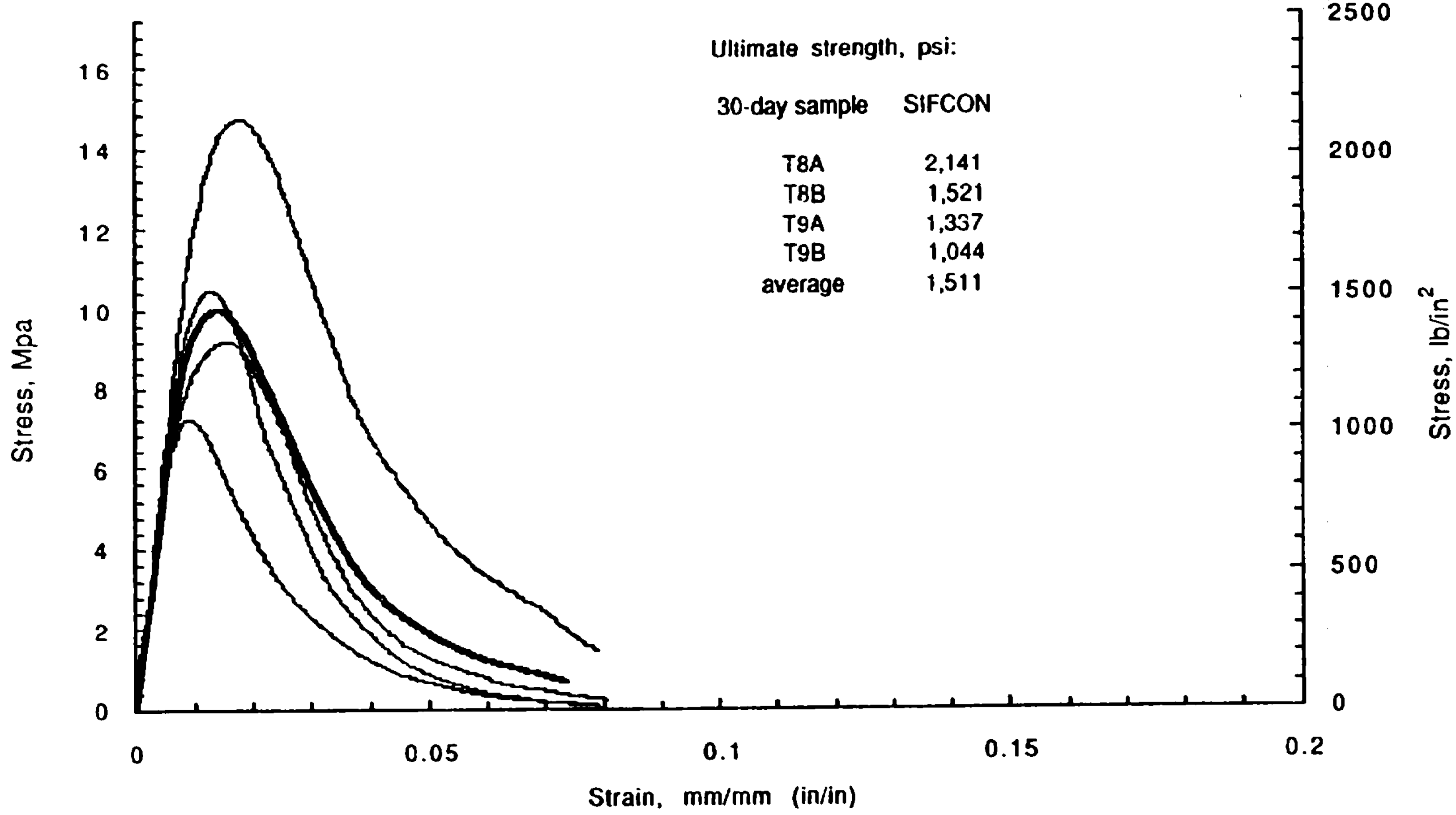


Figure C94. FAC 35-30 T (1-in) tension.

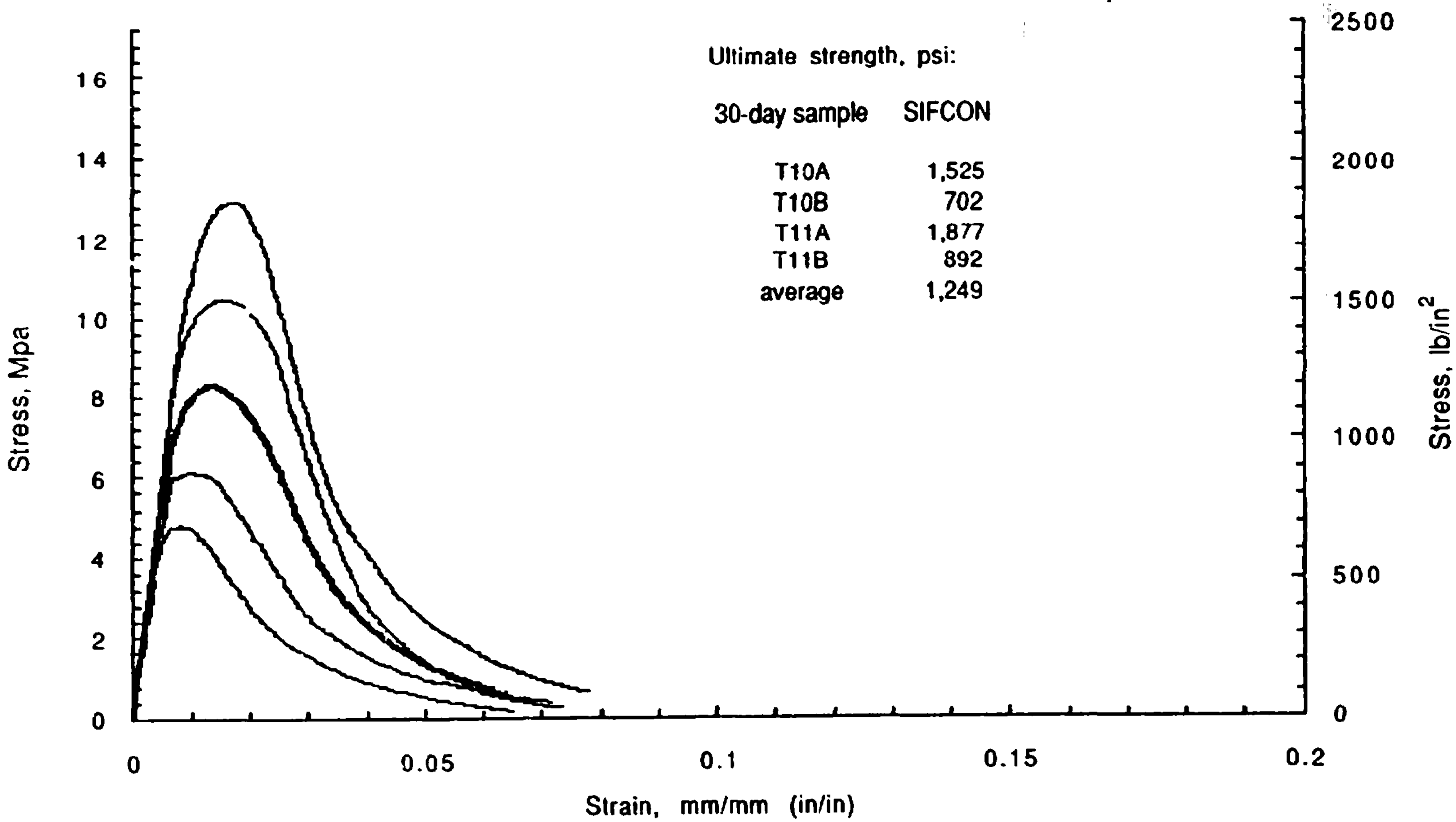


Figure C95. FAC 35-30 T (1.5-in) tension.

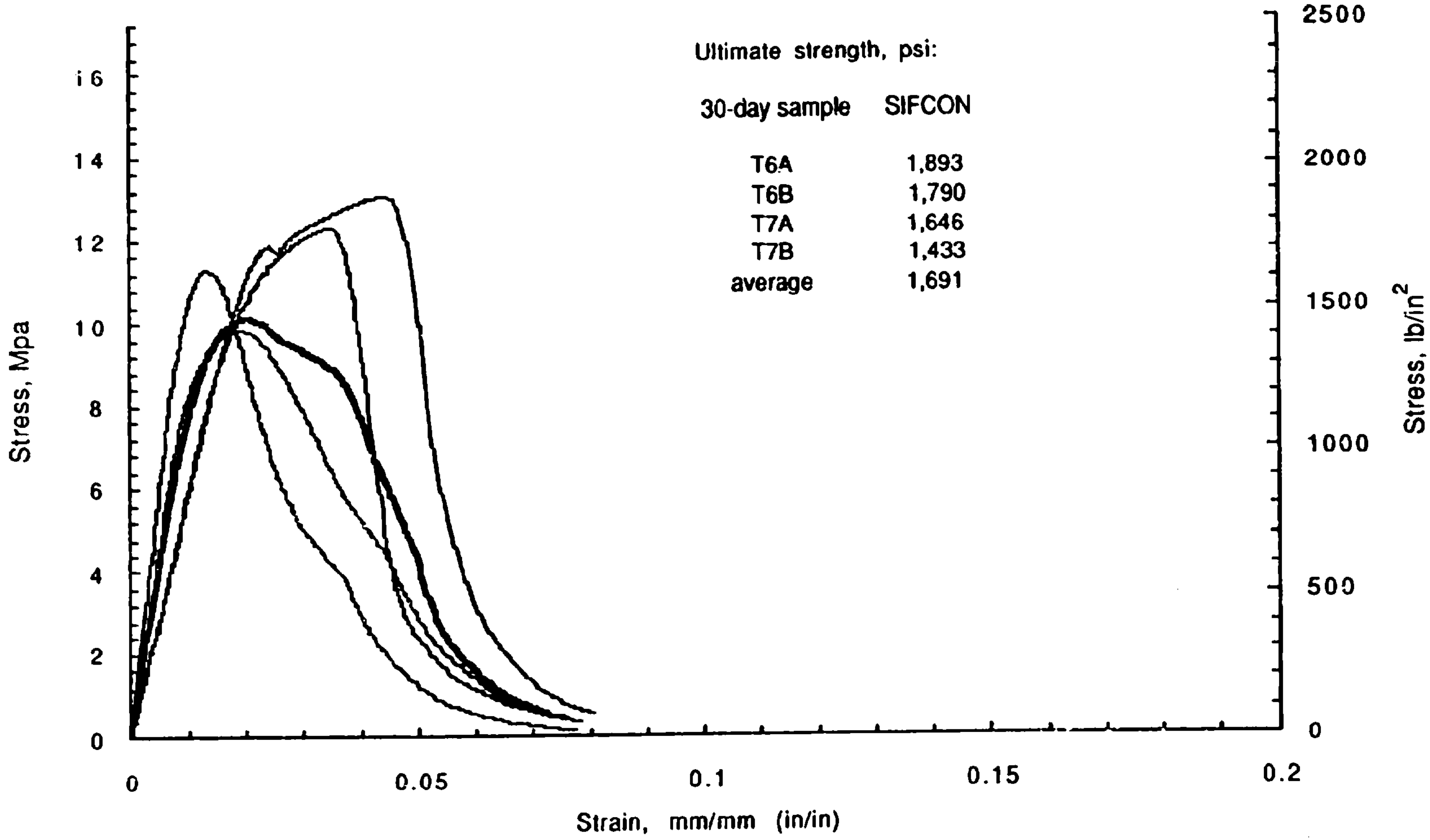


Figure C96. FAC 35-30 T (2-in) tension.

APPENDIX D

TEST RESULTS SUMMARY

This appendix presents a tabulated summary of selected values taken from the 30-day stress/strain and load/deflection curves (Tables D1 through D7). Figures 18 through 21 illustrate generic stress/strain and load/deflection curves showing the location of these selected values for compression, flexure, shear, and tension, respectively.

Tables D1 through D7 are arranged according to mix groups. All values presented are averages of the individual successful test values. The information presented in these tables includes the following:

<u>All types of tests</u>

Mix identification code--Representing each mix design included in each respective study group.

Number of specimens--Actual number of successful specimens tested.

Variation--The range of variation of the strength values of the entire set of the respective successful specimen tests. This value is calculated by taking the percent of the difference between the minimum and maximum values divided by the maximum. This value gives a relative indication of consistency within the set of tests.

<u>Compression tests</u>

Stress and strain, D--The average stress and strain at ultimate SIFCON strength.

Slurry stress--The average ultimate slurry strength.

Stress and strain, A--The average stress and strain at the proportional limit.

Slope 1--The average slope of the elastic portion of the curve, designated as the SIFCON modulus of elasticity.

Stress and strain, B and C--The average stress and strain at the boundaries of the linear, nonelastic portion of the SIFCON compression curve.

Slope 2--The average slope of the linear, nonelastic portion of the SIFCON compression curve.

Flexure tests (most values defined by ASTM C-1018)

Strength and deflection, B--The average calculated strength (modulus of rupture) and measured deflection at ultimate SIFCON strength

Strength and deflection, A--The average calculated strength and measured deflection at the first crack point.

Slope--The average slope of the elastic portion of the curve, designated as the flexure modulus of elasticity.

First-crack toughness--The average calculated area (energy equivalent) under the load/deflection curve to the first crack.

Toughness index, I_5, I_{10} and I_{30}--The average index value obtained by dividing the area under the load/deflection curve up to a deflection of 3.0, 5.5, and 15.5 times the first crack deflection, respectively, by the first crack toughness.

Index ratios, I_{10}/I_5 and I_{10}/I_{30}--The average ratios of the respective toughness indexes.

Shear Tests

Load A--The average load and deflection at ultimate SIFCON shear load.

Tension tests

Stress A--The average ultimate SIFCON tension strength.

Table D8 presents a tabulated summary of all slurry 7-day ultimate strengths. This table is similar to Tables D1-D7.

Table D9 presents a tabulation of strength comparison values for ultimate strength for SIFCON and slurry. The comparison values are in the form of simple ratios. The legend at the top of the table defines the parameters compared. The first group of parameters (S, T, U) compares the SIFCON and slurry compression results of this program. The second group of

parameters (V, W, X) compares compression results of this program with the results of the previous program where there are identical mixes in the two programs. The third group of parameters (Y, Z) compares the flexural test results with the adjusted compression results of this program. Tabulations are presented for each variable group. Following is a calculated average along with the maximum and minimum values.

Table D10 lists the formulas used in computing the various flexure parameters. These parameters are defined in ASTM C-1018.

TABLE D1. STRENGTH SUMMARY--STUDY GROUP 1

Water/cement + fly ash

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in^2	Strain D	Number of cubes	Variation, percent	Stress, lb/in^2	Stress A, lb/in^2	Strain A	Slope 1, (x1000)	Stress B, lb/in^2	Strain B	Slope 2, (x1000)	Stress C, lb/in^2	Strain C
CW 28-30	4	11.39	12,395	0.052	3	1.76	10,475	9,381	0.010	995	11,443	0.021	32	12,383	0.046
FAC 30-30 F	4	18.16	11,825	0.046	3	10.15	9,356	8,611	0.009	1,130	10,391	0.017	61	11,747	0.038
CW 33-30	4	5.17	12,048	0.052	3	7.41	8,543	8,324	0.010	997	10,411	0.020	60	12,013	0.046
FAC 35-30 C	4	9.59	12,773	0.061	2	8.08	7,360	7,003	0.007	1,093	9,464	0.017	83	12,635	0.056
FAC 35-30 D	4	12.89	9,452	0.043	3	16.04	6,950	6,545	0.007	1,051	7,773	0.013	66	9,330	0.037
FAC 35-30 E (typ)	4	9.84	13,613	0.051	3	5.54	6,862	7,860	0.008	1,064	10,396	0.017	104	13,562	0.047
FAC 35-30 F	4	7.67	13,430	0.070	3	3.69	8,109	7,153	0.008	989	9,478	0.018	82	13,360	0.066
FAC 35-30 S	4	16.60	10,434	0.042	2	1.32	8,427	7,403	0.008	1,000	8,743	0.014	65	10,378	0.039
FAC 35-30 T	4	9.56	10,253	0.047	3	7.28	8,780	7,005	0.007	1,029	8,765	0.016	54	10,203	0.043
Z3/5-35-30 F	4	11.28	10,353	0.043	3	0.92	7,004	7,573	0.009	887	9,368	0.020	51	10,303	0.038
CW 38-30	4	2.43	11,063	0.050	3	6.65	6,249	7,245	0.008	1,040	9,053	0.016	65	11,008	0.046
FAC 40-30 F	4	24.55	8,763	0.035	2	1.42	7,065	5,808	0.006	1,049	7,263	0.012	69	8,700	0.032
CW 43-30	4	8.98	8,540	0.028	3	6.36	6,245	6,230	0.007	1,037	8,090	0.017	50	8,508	0.025

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in^2	Defl., B	Strength A, lb/in^2	Defl., A	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
CW 28-30	4	13.39	5,508	0.113	3,808	0.060	430	730	2.795	7.811	16.507	3.091	2.205
FAC 30-30 F	4	20.48	4,600	0.087	2,839	0.034	467	264	5.268	11.22[illegible]	21.610	2.119	1.918
CW 33-30	5	14.94	5,792	0.109	3,236	0.039	463	343	1.617	4.506	11.823	3.717	4.760
FAC 35-30 D(4")	5	26.00	4,267	0.081	2,766	0.033	467	260	5.730	11.904	20.806	2.079	1.747
FAC 35-30 F	5	14.18	5,116	0.083	2,838	0.028	541	216	7.378	15.538	29.645	2.110	1.907
Z3/5-35-30 F	5	22.23	5,149	0.086	3,415	0.037	512	348	9.382	15.447	24.436	1.741	1.546
CW 38-30	5	25.85	4,616	0.092	2,755	0.030	534	237	6.270	13.268	23.321	2.136	1.763
FAC 40-30 F	5	22.28	3,939	0.079	2,307	0.027	444	169	6.239	13.090	26.424	2.101	2.019
CW 43-30	5	31.12	4,575	0.091	2,809	0.038	410	299	6.812	12.938	20.896	1.935	1.633

TABLE D2. STRENGTH SUMMARY–STUDY GROUP 2

2a–Fly ash/cement (W/C+FA=0.30)

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C					
	SIFCON				Slurry			SIFCON								
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 30-0 F	4	13.07	16,146	0.035	3	4.31	13,091	10,150	0.009	1,191	14,768	0.021	126	16,065	0.032
FAC 30-10 F	4	5.00	16,225	0.031	3	9.22	12,749	12,640	0.012	1,135	15,500	0.021	84	16,188	0.029
FAC 30-30 F	4	18.16	11,825	0.046	3	10.15	9,356	8,611	0.009	1,130	10,391	0.017	61	11,747	0.038
FAC 30-50 F	4	7.51	8,747	0.095	3	6.69	6,963	5,908	0.009	772	7,428	0.024	27	8,665	0.080
FAC 30-80 F	NO DATA AVAILABLE				3	0.64	5,435								

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in²	Defl., B	Strength A, lb/in²	Defl., A	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 30-0 F	5	12.42	5,289	0.085	2,689	0.025	577	182	6.032	15.129	31.365	2.524	2.084
FAC 30-10 F	4	11.70	5,308	0.083	2,346	0.022	574	149	5.275	14.846	38.119	2.872	2.628
FAC 30-30 F	4	20.48	4,600	0.077	2,839	0.034	467	264	5.268	11.221	21.610	2.119	1.918
FAC 30-50 F	3	10.71	4,440	0.113	2,157	0.028	402	156	7.077	17.275	39.676	2.457	2.316

TABLE D2. CONTINUED

2b–Fly ash/cement (W/C+FA=0.35)

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C					
	SIFCON				Slurry			SIFCON								
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 35-30 C	4	9.59	12,773	0.061	2	8.08	7,360	7,003	0.007	1,093	9,464	0.017	83	12,635	0.056
FAC 35-30 D	4	12.89	9,452	0.043	3	16.04	6,950	6,545	0.007	1,051	7,773	0.013	66	9,330	0.037
FAC 35-30 E(typ)	4	9.84	13,613	0.051	3	5.54	6,862	7,860	0.008	1,064	10,396	0.017	104	13,562	0.047
FAC 35-30 F	4	7.67	13,430	0.070	3	3.69	8,109	7,153	0.008	989	9,478	0.018	82	13,360	0.066
FAC 35-30 S	4	16.60	10,434	0.042	2	1.32	8,427	7,403	0.008	1,000	8,743	0.014	65	10,378	0.039
FAC 35-30 T	4	9.56	10,253	0.047	3	7.28	8,780	7,005	0.007	1,029	8,765	0.016	54	10,203	0.043
Z3/5-35-30 F	4	11.28	10,353	0.043	3	0.92	7,004	7,573	0.009	887	9,368	0.020	51	10,303	0.038

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in²	Defl., B	Strength A, lb/in²	Defl., A	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 35-30 D(4")	5	26.00	4,267	0.081	2,766	0.033	467	260	5.730	11.904	20.806	2.079	1.747
FAC 35-30 F	5	14.18	5,116	0.083	2,838	0.028	541	216	7.378	15.538	29.645	2.110	1.907
Z3/5-35-30 F	5	22.23	5,149	0.086	3,415	0.037	512	348	9.382	15.447	24.436	1.741	1.546

TABLE D2. CONCLUDED

2c--Fly ash/cement (W/C+FA=0.40)

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C					
	SIFCON				Slurry			SIFCON								
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 40-0 F	4	3.00	14,649	0.038	3	6.07	11,071	9,763	0.010	1,073	12,828	0.019	122	14,463	0.033
FAC 40-10 F	4	12.44	9,832	0.081	2	7.07	8,555	4,163	0.005	836	8,098	0.028	38	9,520	0.065
FAC 40-30 F	4	24.55	8,763	0.035	2	1.42	7,065	5,808	0.006	1,049	7,263	0.012	69	8,700	0.032
FAC 40-50 F	4	9.44	8,344	0.074	3	10.87	5,264	4,715	0.007	750	5,685	0.014	48	8,258	0.068
FAC 40-80 F	4	4.39	4,955	0.073	3	8.44	3,167	3,100	0.008	395	3,723	0.016	24	4,850	0.065

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in²	Defl., B in	Strength A, lb/in²	Defl., A in	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 40-0 F	5	11.18	5,057	0.080	2,807	0.030	528	234	5.936	13.741	24.514	2.320	1.782
FAC 40-10 F	4	20.70	5,522	0.078	2,931	0.029	559	237	6.942	15.010	25.423	2.173	1.731
FAC 40-30 F	5	22.28	3,939	0.079	2,307	0.027	444	169	6.239	13.090	26.424	2.101	2.019
FAC 40-50 F	5	26.93	3,493	0.081	1,897	0.029	358	149	8.605	17.671	33.346	2.062	1.886
FAC 40-80 F	4	8.07	2,058	0.116	1,372	0.045	166	172	6.589	13.262	16.889	2.010	1.260

TABLE D3. STRENGTH SUMMARY--STUDY GROUP 3

Fiber types

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
Z3/4-35-30 F	3	12.48	10,796	0.082	3	9.23	7,098	6,123	0.007	924	7,557	0.015	49	10,723	0.079
Z3/5-35-30 F	4	11.28	10,353	0.043	3	0.92	7,004	7,573	0.009	887	9,368	0.020	51	10,303	0.038
FAC 35-30 C	4	9.59	12,773	0.061	2	8.08	7,360	7,003	0.007	1,093	9,464	0.017	83	12,635	0.056
FAC 35-30 D	4	12.89	9,452	0.043	3	16.04	6,950	6,545	0.007	1,051	7,773	0.013	66	9,330	0.037
FAC 35-30 E(typ)	4	9.84	13,613	0.051	3	5.54	6,862	7,860	0.008	1,064	10,396	0.017	104	13,562	0.047
FAC 35-30 F	4	4.00	13,430	0.070	3	3.64	8,109	7,153	0.008	989	9,478	0.018	82	13,360	0.066
FAC 35-30 S	4	16.60	10,434	0.042	2	1.32	8,427	7,403	0.008	1,000	6,743	0.014	65	10,378	0.039
FAC 35-30 T	4	9.56	10,253	0.047	3	7.28	8,780	7,005	0.007	1,029	8,765	0.016	54	10,203	0.043
Z5/5-35-30 F	4	4.34	7,831	0.022	3	10.36	5,509	7,208	0.008	974	7,668	0.012	21	7,825	0.019
Z5/5-35-30 E(typ)	4	6.58	8,568	0.033	3	5.54	6,862	7,070	0.008	956	7,845	0.013	39	8,528	0.030
Z6/8-35-30 F	4	8.13	7,424	0.009	3	11.78	8,081	7,090	0.007	1,158	7,318	0.007	85	7,395	0.008
OL-35-30 F	4	7.50	13,885	0.087	3	9.23	7,098	6,929	0.007	109	8,615	0.016	78	13,840	0.083
X11-35-30 F	3	25.00	13,418	0.090	3	10.36	5,509	3,403	0.007	508	6,363	0.021	115	13,080	0.081
X12-35-30 F	4	5.51	7,870	0.058	3	1.46	8,503	6,533	0.008	916	7,590	0.017	6	7,845	0.053
X21-35-30 F	4	19.81	6,209	0.010	3	11.78	8,081	5,400	0.006	938	6,070	0.008	122	6,190	0.009
X22-35-30 F	4	12.76	6,296	0.008	3	0.92	7,004	5,960	0.007	941	6,218	0.007	159	6,268	0.008
FB 35-30 F	4	5.91	8,667	0.023	3	9.23	7,098	6,703	0.007	1,071	8,413	0.015	39	8,638	0.021

TABLE D3. CONCLUDED

Fiber types

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in^2	Defl., B	Strength A, lb/in^2	Defl., A	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
Z3/4-35-30 F	5	14.57	4,358	0.100	2,563	0.036	398	245	6.444	13.562	24.838	2.124	1.829
Z3/5-35-30 F	5	22.23	5,149	0.086	3,415	0.037	512	348	9.382	15.447	24.436	1.741	1.546
FAC 35-30 D(4")	5	26.00	4,267	0.081	2,766	0.033	467	260	5.730	11.904	20.806	2.079	1.747
FAC 35-30 F	5	14.18	5,116	0.083	2,838	0.028	541	216	7.378	15.538	29.645	2.110	1.907
Z5/5-35-30 F	5	25.19	4,065	0.125	2,451	0.038	367	267	8.859	15.640	32.658	2.061	2.046
Z5/5-35-30 F (large)	5	20.51	3,470	0.160	1,308	0.029	482	205	11.302	29.285	67.741	2.620	2.362
Z6/8-35-30 F	5	35.36	3,307	0.104	1,407	0.019	419	80	7.772	19.330	57.810	2.516	3.016
Z6/8-35-30 F (large)	5	34.75	3,341	0.152	1,344	0.035	440	265	8.760	21.770	50.176	2.510	2.336
OL-35-30 F	4	6.26	3,381	0.059	2,034	0.025	437	144	3.058	6.388	15.841	2.480	3.270
X11-35-30 F	5	29.41	2,281	0.051	1,986	0.033	349	184	3.941	7.287	12.848	1.848	1.754
X12-35-30 F	5	22.43	2,605	0.093	1,303	0.020	371	73	9.810	21.345	58.073	2.190	2.760
X12-35-30 F (large)	5	15.54	2,201	0.137	1,030	0.031	383	175	12.628	28.108	67.075	2.233	2.378
X21-35-30 F	5	30.82	1,871	0.037	777	0.010	275	36	10.055	18.929	34.422	1.912	1.824
X22-35-30 F	4	12.82	2,293	0.040	1,173	0.016	412	54	6.375	14.280	31.593	2.279	2.217
X22-35-30 F (large)	5	26.30	1,867	0.088	1,141	0.041	311	257	7.577	14.356	20.240	1.878	1.305
FB 35-30 F	4	11.74	3,360	0.054	1,752	0.021	450	106	8.486	15.952	27.541	1.900	1.733

TABLE D4. STRENGTH SUMMARY--STUDY GROUP 4

4a--Sand types

COMPRESSION

COMPARISON SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
FAC 35-30 C	2	8.08	7360
FAC 35-30 D	3	16.04	6950
FAC 35-30 E(typ)	3	5.54	6862
FAC 35-30 F	3	3.69	8109
FAC 35-30 S	2	1.32	8427
FAC 35-30 T	3	7.28	8780
Z3/5-35-30 F	3	0.92	7004
Average		21.85	7642

BRICK SAND SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
S1-0-35-30	3	3.62	8226
S1-25-35-30	3	3.19	8213
S1-50-35-30	3	1.90	7907
S1-75-35-30	3	4.05	7447
S1-100-35-30	3	6.62	7387
S1-125-35-30	3	4.72	7515
S1-150-35-30	3	6.08	7791
Average		10.20	7784

PLASTER SAND SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
S2-0-35-30	3	12.16	7539
S2-25-35-30	3	3.75	7798
S2-50-35-30	3	7.48	6939
S2-75-35-30	3	9.30	7026
S2-100-35-30	3	7.70	7062
S2-125-35-30	3	5.92	7164
S2-150-35-30	3	7.98	7244
Average		11.02	7253

COARSE BLASTING SAND SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
S3-0-35-30	3	14.02	8203
S3-25-35-30	3	4.87	7640
S3-50-35-30	3	4.56	7596
S3-75-35-30	3	2.58	7524
S3-100-35-30	3	4.83	7563
S3-125-35-30	3	1.53	7521
S3-150-35-30	3	8.39	6928
Average		15.54	7568

MEDIUM BLASTING SAND SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
S4-0-35-30	3	16.61	6682
S4-25-35-30	3	13.22	7769
S4-50-35-30	3	9.97	7015
S4-75-35-30	3	6.79	7355
S4-100-35-30	3	14.82	7075
S4-125-35-30	3	12.73	7102
S4-150-35-30	3	8.17	6966
Average		13.99	7138

FINE BLASTING SAND SLURRY

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in^2
S5-0-35-30	3	2.79	8613
S5-25-35-30	3	4.08	7956
S5-50-35-30	3	4.15	7621
S5-75-35-30	3	12.90	7581
S5-100-35-30	3	10.50	7439
S5-125-35-30	3	4.30	7264
S5-150-35-30	3	2.81	7519
Average		15.66	7713

Note: The mix identification codes are misleading. They indicate a lower sand percentage than was present. Refer to Table A4.

TABLE D4. CONTINUED

4b–Brick Sand (W/C+FA=0.30)

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 30-30 F	4	18.16	11,825	.046	3	10.15	9,356	8,611	.009	1,130	10,391	.017	61	11,747	.038
S 25-30-30 F	4	15.01	12,700	.038	2	7.00	6,942	8,910	.008	1,233	11,548	.018	65	12,635	.035
S 50-30-30 F	4	7.91	12,230	.034	3	1.02	8,860	8,613	.008	1,148	11,143	.018	778	12,170	.031
S 75-30-30 F	4	6.67	13,532	.032	3	6.28	8,373	9,218	.007	1,329	12,048	.016	99	13,465	.030

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in²	Defl., B in	Strength A, lb/in²	Defl., A in	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 30-30 F	5	0.20	4,600	0.087	2,839	0.034	467	264	5.268	11.221	21.610	2.119	1.918
S 25-30-30 F	5	0.19	5,677	0.097	3,710	0.037	556	387	8.671	15.332	27.258	1.822	1.757
S 50-30-30 F	5	0.24	5,030	0.085	2,998	0.032	547	275	7.424	14.503	23.328	1.995	1.625
S 75-30-30 F	5	0.27	6,158	0.084	3,584	0.032	631	338	9.536	16.979	29.742	2.048	1.776

TABLE D4. CONCLUDED

4c–Brick sand (W/C+FA=0.40)

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 40-30 F	4	24.55	8,763	0.035	3	1.42	7,065	5,808	0.006	1,049	7,263	0.012	69	8,700	0.032
S 50-40-30 F	4	8.90	12,317	0.040	3	7.02	6,163	7,550	0.009	949	10,070	0.017	120	12,138	0.034
S 100-40-30 F	4	10.90	12,3[illegible]	0.042	3	3.72	5,957	6,845	0.008	961	9,503	0.017	133	12,178	0.037
S 150-40-30 F	4	6.62	12,877	0.029	3	3.00	6,177	8,618	0.009	1,094	12,380	0.022	89	12,808	0.026
S 200-40-30 F	NO DATA AVAILABLE				3	9.42	6,434								

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in²	Defl., B in	Strength A, lb/in²	Defl., A in	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 40-30 F	4	.22	3,939	0.079	2,307	0.027	444	169	6.239	13.090	26.424	2.101	2.019
S 50-40-30 F	4	.15	4,946	0.077	2,872	0.032	508	249	8.468	16.299	26.683	1.923	1.635
S 100-40-30 F	4	.15	4,713	0.069	2,603	0.026	570	182	7.576	15.986	32.696	2.104	2.038
S 150-40-30 F	4	.04	5,106	0.079	2,795	0.025	606	195	8.777	17.703	29.801	2.028	1.696
S 200-40-30 F	2	.01	4,394	0.154	3,646	0.101	171	955	.795	2.230	6.565	2.990	3.557

TABLE D5. STRENGTH SUMMARY--STUDY GROUP 5

Composite beams

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C					
	SIFCON				Slurry			SIFCON								
	Number of cores	Variation, percent	Stress D, lb/in	Strain D	Number of cubes	Variation, percent	Stress, lb/in^2	Stress A, lb/in^2	Strain A	Slope 1, (x1000)	Stress B, lb/in^2	Strain B	Slope 2, (x1000)	Stress C, lb/in^2	Strain C
FAC 35-30 C	4	9.59	12,773	.061	2	8.08	7,360	7,003	.007	1,093	9,464	.017	83	12,635	.056
FAC 35-30 F	4	7.67	13,430	.070	3	3.69	8,109	7,153	.008	989	9,478	.018	82	13,360	.066

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in^2	Defl., B in	Strength A, lb/in^2	Defl., A in	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 35-30 F	5	14.18	5,116	0.083	2,838	0.028	541	216	7.378	15.538	29.645	2.110	1.907
C 3-35-30 F	5	20.70	4,216	0.133	2,918	0.057	263	456	5.931	11.105	15.652	1.908	1.416
C 2-35-30 F	5	20.72	3,907	0.114	2,495	0.041	321	269	8.222	15.174	17.796	1.853	1.115
C 1.5-35-30 F	5	21.29	3,191	0.106	2,039	0.043	244	241	9.516	13.652	-	1.387	-
C 1-35-30 F	5	36.75	2,446	0.095	1,588	0.039	224	170	6.595	11.836	-	1.753	-
C 0.5-35-30 F	4	45.48	1,900	0.077	1,516	0.039	197	161	6.091	8.005	-	1.316	-
C 0-35-30 C	2	6.10	573		ADDITIONAL DATA NOT APPLICABLE								
C 0-35-30 F	2	15.51	768		ADDITIONAL DATA NOT APPLICABLE								

TABLE D6. STRENGTH SUMMARY--STUDY GROUP 6

Variable depth beams

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C					
	SIFCON				Slurry			SIFCON								
	Number of cores	Variation, percent	Stress D, lb/in2	Strain D	Number of cubes	Variation, percent	Stress, lb/in2	Stress A, lb/in	Strain A	Slope 1, (x1000)	Stress B, lb/in2	Strain B	Slope 2, (x1000)	Stress C, lb/in2	Strain C
FAC 35-30 D	4	12.89	9,452	0.043	3	16.04	6,950	6,545	0.007	1,051	7,773	0.013	66	9,330	0.037

FLEXURE

Mix identification code	Ultimate strength				1st Crack				Toughness index			Index ratios	
	Number of beams	Variation, percent	Strength B, lb/in2	Defl., B in	Strength A, lb/in2	Defl., A in	Slope, (x1000)	Toughness in-lb	I5	I10	I30	I10/I5	I30/I10
FAC 35-30 D(1")	5	34.65	3,313	0.209	1,574	0.033	17	9	14.890	32.134	57.479	2.167	1.799
FAC 35-30 D(2")	4	9.16	4,025	0.138	2,993	0.059	68	122	5.466	10.787	-	1.980	-
FAC 35-30 D(3")	3	24.23	3,597	0.105	2,475	0.042	237	190	4.466	9.899	18.944	2.231	1.919
FAC 35-30 D(4")	5	26.00	4,267	0.081	2,766	0.033	467	260	5.730	11.904	20.806	2.079	1.747
FAC 35-30 D(4"L)	5	17.09	4,182	0.141	2,845	0.059	217	355	4.913	10.463	19.296	2.238	1.897
FAC 35-30 D(5")	5	13.18	4,632	0.100	2,918	0.039	653	529	4.900	10.884	17.877	2.269	1.656

TABLE D7. STRENGTH SUMMARY--STUDY GROUPS 7-9

Study Group 7–Edge effects

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 35-30 E (typ)	4	9.84	13,613	0.051	3	5.539	6,862	7,860	0.008	1,064	10,396	0.017	104	13,562	0.047
FAC 35-30 E(con)	4	7.66	13,839	0.056	3	5.539	6,862	7,782	0.008	1,031	9,520	0.014	110	13,797	0.053
Z 5/5-35-30 E (typ)	4	6.58	8,568	0.033	3	5.539	6,862	7,070	0.008	956	7,845	0.013	39	8,528	0.030
Z 5/5-35-30 E (con)	4	6.79	9,017	0.039	3	5.539	6,862	6,683	0.007	1,012	7,745	0.012	56	8,955	0.034

STUDY GROUPS 8-9–Shear and tension tests

COMPRESSION

Mix identification code	Ultimate strength							Proportional limit			Points B and C				
	SIFCON				Slurry			SIFCON							
	Number of cores	Variation, percent	Stress D, lb/in²	Strain D	Number of cubes	Variation, percent	Stress, lb/in²	Stress A, lb/in²	Strain A	Slope 1, (x1000)	Stress B, lb/in²	Strain B	Slope 2, (x1000)	Stress C, lb/in²	Strain C
FAC 35-30 S	4	16.60	10,434	0.042	2	1.32	8,427	7,403	0.008	1,000	8,743	0.014	65	10,378	0.039
FAC 35-30 T	4	9.56	10,253	0.047	3	7.28	8,780	7,005	0.007	1,029	8,765	0.016	54	10,203	0.043

TABLE D7. CONCLUDED

SHEAR

Mix identification code	Ultimate strength SIFCON: Number of tests	Variation, percent	Load, lbf	Calculated average stress, lb/in²
FAC 35-30 T				
4"	4	8.81	53,625	1650
4"(partial)	3	4.76	57,000	1780
4"(restrained)	3	4.91	63,933	1953
FAC 35-30 S				
4"	4	11.51	81,183	1962
4"(restrained)	1	--	76,800	1854
5"	6	24.54	74,900	1814
5"(restrained)	2	3.18	83,550	2025
6"	2	13.69	66,700	1610
6"(restrained)	3	16.36	69,033	1664
7"(restrained)	4	16.18	67,125	1515
8"(restrained)	4	21.99	44,250	1068

TENSION

Mix identification code	Ultimate strength SIFCON: Number of specimens	Variation, percent	Stress, lb/in²
FAC 35-30 T			
Milled	4	38.77	1,151
1/2"	4	27.15	1,539
3/4"	4	44.57	1,342
1"	4	51.24	1,511
1.5"	4	62.60	1,249
2"	4	24.30	1,691
Average			1,414

TABLE D8. SLURRY 7-DAY COMPRESSIVE STRENGTH

Study Group 1--Water / cement + fly ash

Mix identification code	Slurry ultimate strength		
	Number of cubes	Variation, percent	Stress, lb/in
CW 28-30	3	19.15	7182
CW 33-30	3	9.96	6394
CW 38-30	3	12.72	4863
CW 43-30	3	5.28	3915

Study Group 2--Fly ash / cement

Subgroup 2a (W/C+FA = 0.30)

Mix identification code	Slurry ultimate strength		
	Number of cubes	Variation, percent	Stress, lb/in
FAC 30-0 F	2	2.51	9546
FAC 30-10 F	0		
FAC 30-30 F	3	12.89	6482
FAC 30-50 F	3	3.34	4945
FAC 30-80 F	3	17.21	3539

Subgroup 2b (W/C+FA = 0.35)

Mix identification code	Slurry ultimate strength		
	Number of cubes	Variation, percent	Stress, lb/in
FAC 35-30 C	3	8.19	5567
FAC 35-30 D	3	30.46	6340
FAC 35-30 E(typ)	0		
FAC 35-30 F	3	5.53	5569
FAC 35-30 S	3	1.13	6534
FAC 35-30 T	3	4.41	6410

Subgroup 2c (W/C+FA = 0.40)

Mix identification code	Slurry ultimate strength		
	Number of cubes	Variation, percent	Stress, lb/in
FAC 40-0 F	3	4.58	7029
FAC 40-10 F	3	13.74	6786
FAC 40-30 F	3	10.48	4852
FAC 40-50 F	3	9.60	3869
FAC 40-80 F	3	2.80	2312

TABLE D8. CONCLUDED

Study Group 3–Fiber types

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in
Z3/4-35-30 F	3	3.89	4940
Z3/5-35-30 F	0		
Z5/5-35-30 F	3	11.37	4974
Z5/5-35-30 E (typ)	Same as FAC 35-30 E(typ)		
Z6/8-35-30 F	3	5.42	6423
OL-35-30 F	Same as Z3/4-35-30 F		
X11-35-30 F	Same as Z5/5-35-30 F		
X12-35-30 F	3	15.32	6229
X21-35-30 F	Same as Z6/8-35-30 F		
X22-35-30 F	Same as Z3/5-35-30 F		
FB 35-30 F	Same as Z3/4-35-30 F		

Study Group 4–Sand

Subgroup 4a (Sand types)

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in
S1-0-35-30	3	18.33	5471
S2-0-35-30	2	2.35	5166
S3-0-35-30	3	17.72	5498
S4-0-35-30	3	3.25	5385
S5-0-35-30	3	6.94	5511

Subgroup 4b (W/C+FA = 0.30)

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in
S 25-30-30 F	3	3.75	6372
S 50-30-30 F	3	2.20	6712
S 75-30-30 F	3	16.75	5671

Subgroup 4c (W/C+FA = 0.40)

Mix identification code	Slurry ultimate strength: Number of cubes	Variation, percent	Stress, lb/in
S 50-40-30 F	3	15.11	4033
S 100-40-30 F	3	1.53	4246
S 150-40-30 F	3	1.37	4378
S 200-40-30 F	3	10.25	4792

TABLE D9. STRENGTH COMPARISON SUMMARY

Legend:
S = SIFCON / slurry strength at 30 days
T = 30-day / 7-day strength of slurry
U = 30-day SIFCON / 7-day slurry strength
V = Present / previous program for 30-day SIFCON
W = Present / previous program for 30-day slurry
X = Present / previous program for 7-day slurry
Y = Modulus of rupture / 1st crack strength at 30 days
Z = Compression (adjusted) / modulus of rupture at 30 days

NOTE: All calculations based on ultimate strength values except as noted.

Study Group 1--Water / cement + fly ash

Present program -- compression compared				Previous program -- compared				Flexure compared	
Identification	S	T	U	Identification	V	W	X	Y	Z
CW 28-30	1.183	1.4585	1.7258					1.446	2.866
FAC 30-30 F	1.264	1.4434	1.8243	FAC 30-30	0.704	1.037	0.983	1.621	3.652
CW 33-30	1.410	1.3361	1.8842					1.790	2.649
FAC 35-30 C	1.735	1.3221	2.2944	FAC 35-30	0.901	1.006	1.400		2.715
FAC 35-30 D	1.360	1.0962	1.4908					1.543	
FAC 35-30 E(typ)	1.984								
FAC 35-30 F	1.656	1.4561	2.4116					1.803	
FAC 35-30 S	1.238	1.2897	1.5968						
FAC 35-30 T	1.168	1.3697	1.5996						
Z3/5-35-30 F	1.478							1.507	2.561
CW 38-30	1.770	1.2850	2.2749					1.675	3.052
FAC 40-30 F	1.240	1.4561	1.8061	FAC 40-30	0.703	0.950	0.881	1.707	3.166
CW 43-30	1.367	1.5951	2.1812					1.629	2.377
Minimum	1.168	1.0962	1.4908		0.703	0.950	0.881	1.446	2.377
Maximum	1.984	1.5951	2.4116		0.901	1.037	1.400	1.803	3.652
Average	1.450	1.3735	1.9172		0.769	0.998	1.088	1.636	2.880

TABLE D9. CONTINUED

Study Group 2--Fly ash / cement
Subgroup 2a (W / C + FA = 0.30)

Present program -- compression compared			
Identification	S	T	U
FAC 30-0 F	1.233	1.371	1.691
FAC 30-10 F	1.273		
FAC 30-30 F	1.264	1.443	1.824
FAC 30-50 F	1.256	1.408	1.769
FAC 30-80 F			
Minimum	1.233	1.371	1.691
Maximum	1.273	1.443	1.824
Average	1.257	1.408	1.761

Previous program -- compared			
Identification	V	W	X
FAC 30-0	0.746	0.864	0.841
FAC 30-10	0.872	1.087	
FAC 30-30	0.704	1.037	0.983
FAC 30-50	0.720	1.065	1.048
FAC 30-80			0.793
	0.704	0.864	0.793
	0.872	1.087	1.048
	0.761	1.013	0.916

Flexure compared	
Y	Z
1.967	4.091
2.263	3.893
1.621	3.652
2.059	2.738
1.621	2.738
2.263	4.091
1.977	3.59[illegible]

Subgroup 2b (W / C + FA = 0.35)

Present program -- compression compared			
Identification	S	T	U
FAC 35-30 C	1.735	1.322	2.294
FAC 35-30 D	1.360	1.096	1.491
FAC 35-30 E(typ)	1.984		
FAC 35-30 F	1.656	1.456	2.412
FAC 35-30 S	1.238	1.290	1.597
FAC 35-30 T	1.168	1.370	1.600
Z3/5-35-30 F	1.478		
Minimum	1.168	1.096	1.491
Maximum	1.984	1.456	2.412
Average	1.517	1.307	1.879

Previous program -- compared			
Identification	V	W	X
FAC 35-30	0.901	1.006	1.400
	0.901	1.006	1.400
	0.901	1.006	1.400
	0.901	1.006	1.400

Flexure compared	
Y	Z
	2.715
1.543	
1.803	
1.507	2.561
1.507	2.561
1.803	2.715
1.618	2.638

TABLE D9. CONTINUED

Subgroup 2c (W / C + FA = 0.40)

Present program -- compression compared			
Identification	S	T	U
FAC 40-0 F	1.323	1.575	2.084
FAC 40-10 F	1.149	1.261	1.449
FAC 40-30 F	1.240	1.456	1.806
FAC 40-50 F	1.585	1.361	2.157
FAC 40-80 F	1.565	1.370	2.143
Minimum	1.149	1.261	1.449
Maximum	1.585	1.456	2.157
Average	1.385	1.362	1.889

Previous program -- compared			
Identification	V	W	X
FAC 40-0	0.766	0.988	0.892
FAC 40-10	0.673	0.850	0.864
FAC 40-30	0.703	0.950	0.881
FAC 40-50	0.992	0.947	1.041
FAC 40-80	0.674	1.219	1.204
	0.673	0.850	0.864
	0.992	1.219	1.204
	0.760	0.992	0.997

Flexure compared	
Y	Z
1.801	3.782
1.884	2.647
1.707	3.166
1.841	2.407
1.500	3.574
1.500	2.407
1.884	3.574
1.733	2.948

Subgroups 2a through 2c combined

Present program -- compression compared			
Identification	S	T	U
Minimum	1.149	1.096	1.449
Maximum	1.984	1.575	2.412
Average	1.407	1.368	1.870

Previous program -- compared			
	V	W	X
	0.673	0.850	0.733
	0.992	1.219	1.400
	0.775	1.001	0.995

Flexure compared	
Y	Z
1.500	2.407
2.263	4.091
1.791	3.202

TABLE D9. CONTINUED

Study Group 3--Fiber types

Present program -- compression compared				Previous program -- compared				Flexure compared	
Identification	S	T	U	Identification	V	W	X	Y	Z
Z3/4-35-30 F	1.521	1.437	2.185					1.700	3.155
Z3/5-35-30 F	1.478							1.507	2.561
FAC 35-30 C	1.735	1.322	2.294	FAC 35-30	0.90´	1.006	1.400		2.715
FAC 35-30 D	1.360	1.096	1.491					1.543	
FAC 35-30 E (typ)	1.984								
FAC 35-30 F	1.656	1.456	2.412					1.803	
FAC 35-30 S	1.238	1.290	1.597						
FAC 35-30 T	1.168	1.370	1.600						
Z5/5-35-30 F	1.421	1.108	1.574	ZL 50/50	0.837	0.724	0.873	1.659	2.302
Z5/5-35-30 F(large)								2.653	
Z5/5-35-30 E (typ)	1.249								
Z6/8-35-30 F	0.919	1.258	1.156	ZL 60/80	0.753	1.031	1.084	2.350	2.981
Z6/8-35-30 F(large)								2.486	
OL-35-30 F	1.956	1.437	2.811	OL 20/25	1.023	0.926	0.778	1.662	4.014
X11-35-30 F			2.698	XOR-1				1.149	
X12-35-30 F	0.926	1.365	1.263	XOR-1L	0.627	1.029	1.086	1.999	4.816
X12-35-30 F(large)								2.136	
X21-35-30 F	0.768	1.258	0.967	XOR-2				2.408	4.226
X22-35-30 F	0.899							1.954	3.496
X22-35-30 F(large)								1.636	
FB 35-30 F	1.221	1.437	1.754	FBCN-1	0.788	0.821	0.778	1.917	3.276
Minimum	0.768	1.096	0.967		0.627	0.724	0.778	1.149	2.302
Maximum	1.984	1.456	2.811		1.023	1.031	1.400	2.653	4.816
Average	1.344	1.319	1.831		0.821	0.923	1.000	1.910	3.354

TABLE D9. CONTINUED

Subgroup 4c (W / C + FA = 0.40)

Present program -- compression compared			
Identification	S	T	U
FAC 40-30 F	1.240	1.456	1.806
S 50-40-30 F	1.999	1.528	3.054
S 100-40-30 F	2.078	1.403	2.916
S 150-40-30 F	2.085	1.411	2.941
S 200-40-30 F		1.343	
Minimum	1.240	1.343	1.806
Maximum	2.085	1.528	3.054
Average	1.850	1.428	2.679

Previous program -- compared			
Identification	V	W	X
FAC 40-30	0.703	0.950	0.881

Flexure compared	
Y	Z
1.707	3.166
1.722	3.172
1.811	3.345
1.827	3.212
1.205	
1.205	3.166
1.827	3.345
1.655	3.224

Subgroups 4a through 4c combined

Present program -- compression compared			
Identification	S	T	U
Minimum	1.240	1.089	1.806
Maximum	2.085	1.528	3.054
Average	1.695	1.379	2.343

Previous program -- compared			
Identification	V	W	X
	0.703	0.950	0.881
	0.704	1.037	0.983
	0.703	0.994	0.932

Flexure compared	
Y	Z
1.205	2.799
1.827	3.652
1.647	3.161

TABLE D9. CONTINUED

Study Group 4--Sand
Subgroup 4a (Sand types)

Present program -- compression compared			
Identification	S	T	U
S1-0-35-30		1.504	
S2-0-35-30		1.459	
S3-0-35-30		1.492	
S4-0-35-30		1.241	
S5-0-35-30		1.563	
Minimum		1.241	
Maximum		1.563	
Average		1.452	

Subgroup 4b (W / C + FA = 0.30)

Present program -- compression compared			
Identification	S	T	U
FAC 30-30 F	1.264	1.443	1.824
S 25-30-30F	1.829	1.089	1.993
S 50-30-30 F	1.380	1.320	1.822
S 75-30-30F	1.684	1.417	2.386
Minimum	1.264	1.089	1.822
Maximum	1.829	1.443	2.386
Average	1.540	1.317	2.006

Previous program -- compared			
Identification	V	W	X
FAC 30-30	0.704	1.037	0.983

Flexure compared	
Y	Z
1.621	3.652
1.530	2.849
1.677	3.097
1.718	2.799
1.530	2.799
1.718	3.652
1.637	3.099

TABLE D9. CONCLUDED.

Study Group 7--Edge effects

Present program -- compression compared			
Identification	S	T	U
FAC 35-30 E (typ)	1.984		
FAC 35-30 E(con)	2.017		
Z5/5-35-30 E (typ)	1.249		
Z 5/5-35-30 E (con)	1.314		
Minimum	1.249		
Maximum	2.017		
Average	1.641		

Previous program -- compared			
Identification	V	W	X
FAC 35-30	1.069	0.903	
FAC 35-30	1.087	0.903	
ZL 50/50	0.915	0.902	
ZL 50/50	0.963	0.902	
	0.915	0.902	
	1.087	0.903	
	1.009	0.902	

All mixes combined

Present program -- compression compared			
	S	T	U
Minimum	0.768	1.089	0.967
Maximum	2.085	1.595	3.054
Average	1.446	1.376	1.997

Previous program -- compared			
	V	W	X
	0.627	0.724	0.778
	1.023	1.219	1.400
	0.785	0.970	0.970

Flexure compared	
Y	Z
1.149	2.302
2.653	4.816
1.812	3.204

Notes: 1. Study Groups 5, 6, 8, and 9 are not included separately but their values can be found individually within the study groups that are included.

2. The values contained in "All mixes combined, Previous program - compared" do not include those values from Study Group 7.

TABLE D10. FLEXURE FORMULAS

First-Crack Strength (A) $= \dfrac{(\text{load}_A)(\text{span})}{(\text{width})(\text{depth})^2} = \dfrac{(\text{load}_A)(3\ \text{depth})}{(\text{width})(\text{depth})^2} = \dfrac{3P_A}{bd}$

First-crack deflection $= \zeta$

Modulus of rupture (u) $= \dfrac{(\text{load}_u)(3\ \text{depth})}{(\text{width})(\text{depth})^2} = \dfrac{3P_u}{bd}$

Deflection at ultimate $= \zeta u$

Flexure modulus of elasticity = slope of O'A

First-crack toughness = (Area O'AB) $= \dfrac{(\text{load}_A)(\zeta)}{2} = \dfrac{P_A \zeta_A}{}$

Toughness index $I_5 = \dfrac{(\text{Area}_{O'ADC})}{(\text{1st crack toughness})}$

Toughness index $I_{10} = \dfrac{(\text{Area}_{AO'FE})}{(\text{1st crack toughness})}$

Toughness index $I_{30} = \dfrac{(\text{Area}_{AO'HG})}{(\text{1st crack toughness})}$

Ratio $I_{10}/I_5 = \dfrac{(\text{toughness index } I_{10})}{(\text{toughness index } I_5)}$

Ratio $I_{30}/I_{10} = \dfrac{(\text{toughness index } I_{30})}{(\text{toughness index } I_{10})}$

APPENDIX E

STUDY GROUP 1: WATER/(CEMENT + FLY ASH) RELATIONSHIPS

This appendix presents additional graphical relationships (not contained in the body of the report) of selected compression and flexure strength parameters for Study Group 1 (Figs. E1-E3).

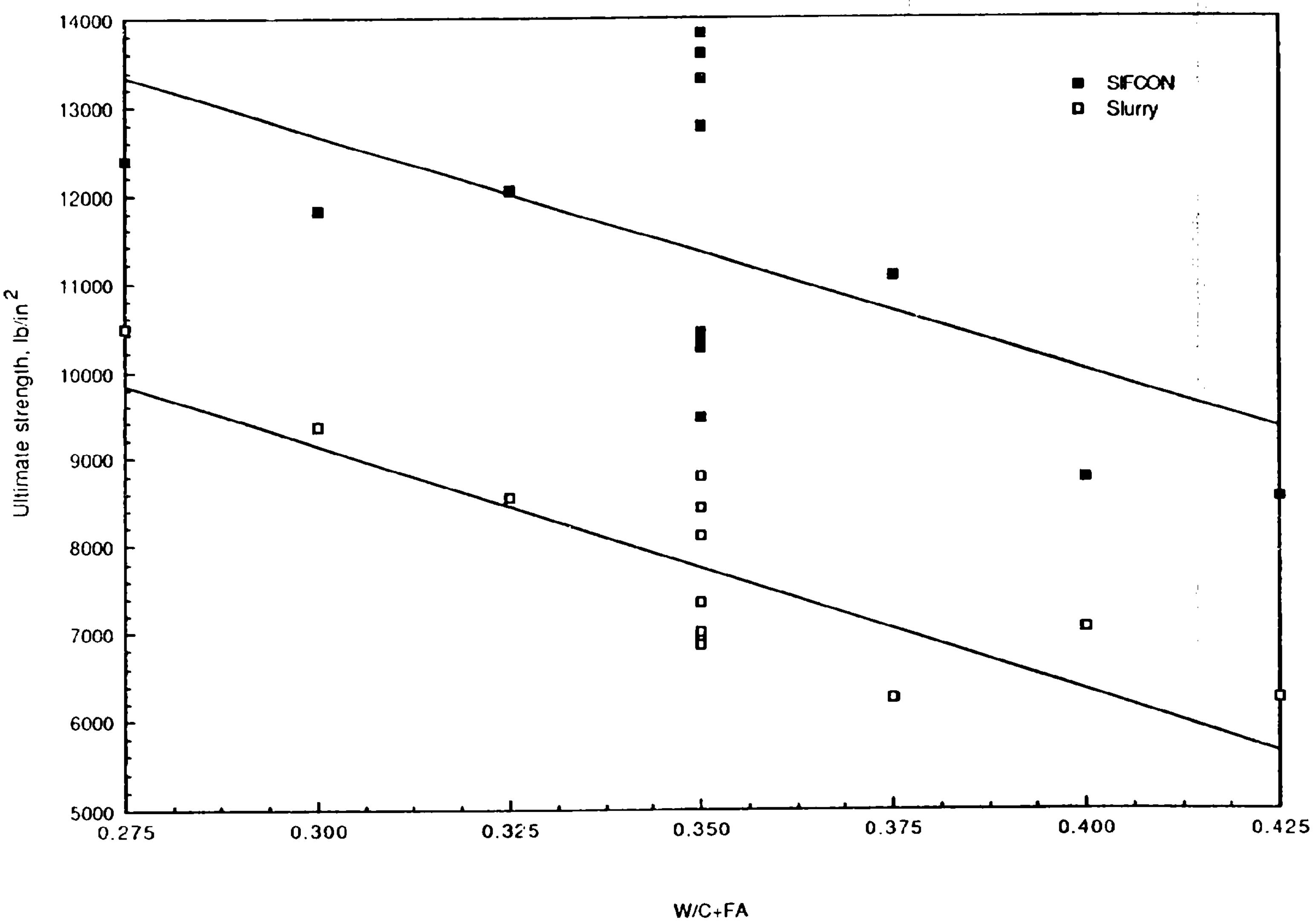


Figure E1. Ultimate compressive strength versus water/(cement + fly ash).

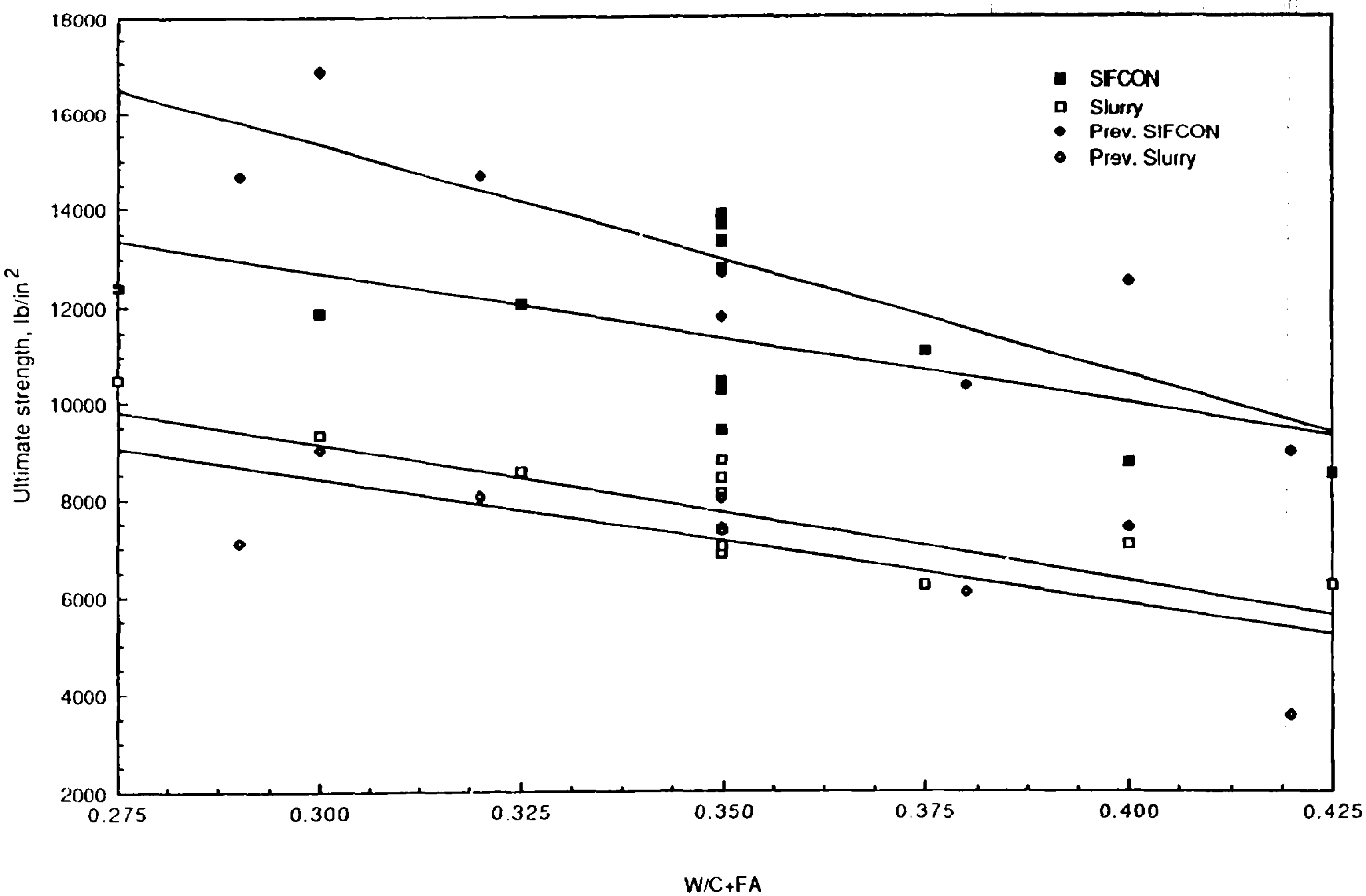


Figure E2. Ultimate compressive strength versus water/(cement+fly ash)--comparison.

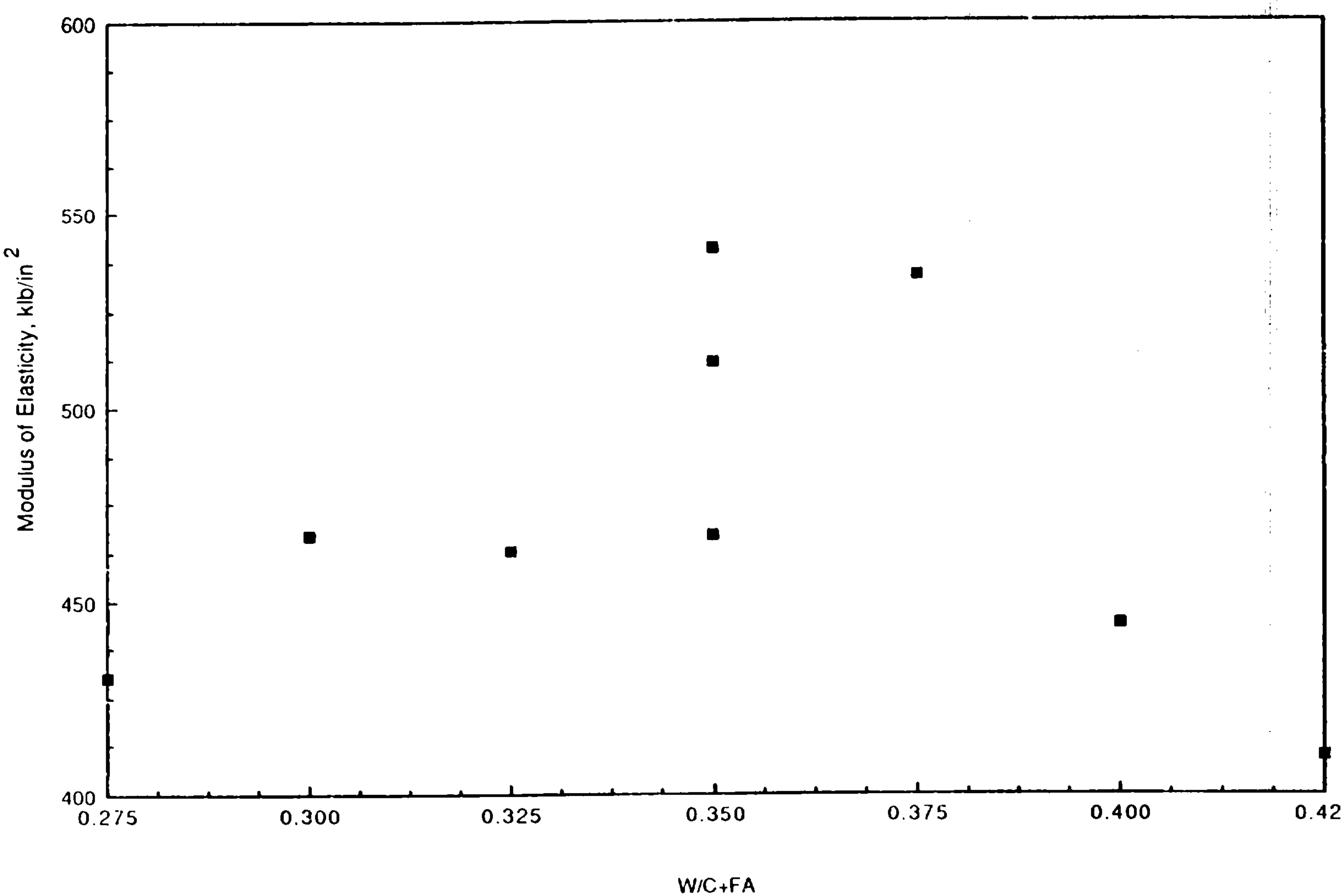


Figure E3. Flexure modulus of elasticity versus water/(cement+fly ash).

APPENDIX F

STUDY GROUP 2: FLY ASH/CEMENT RELATIONSHIPS

This appendix presents additional graphical relationships (not contained in the body of the report) of selected compression and flexure strength parameters for Study Group 2 (Figs. F1-F4).

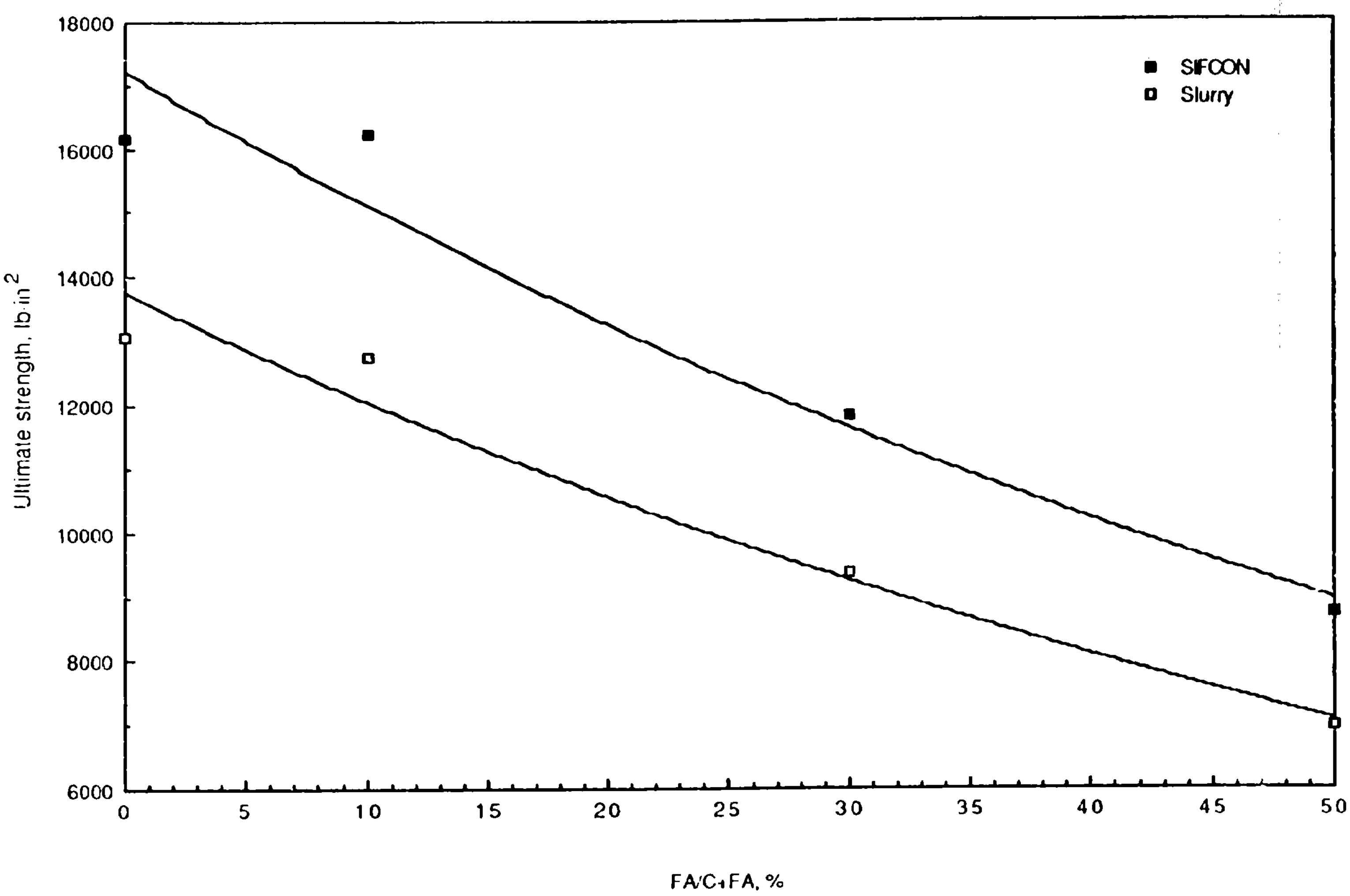


Figure F1. Ultimate compressive strength versus fly ash/cement (W/C + FA = 0.30).

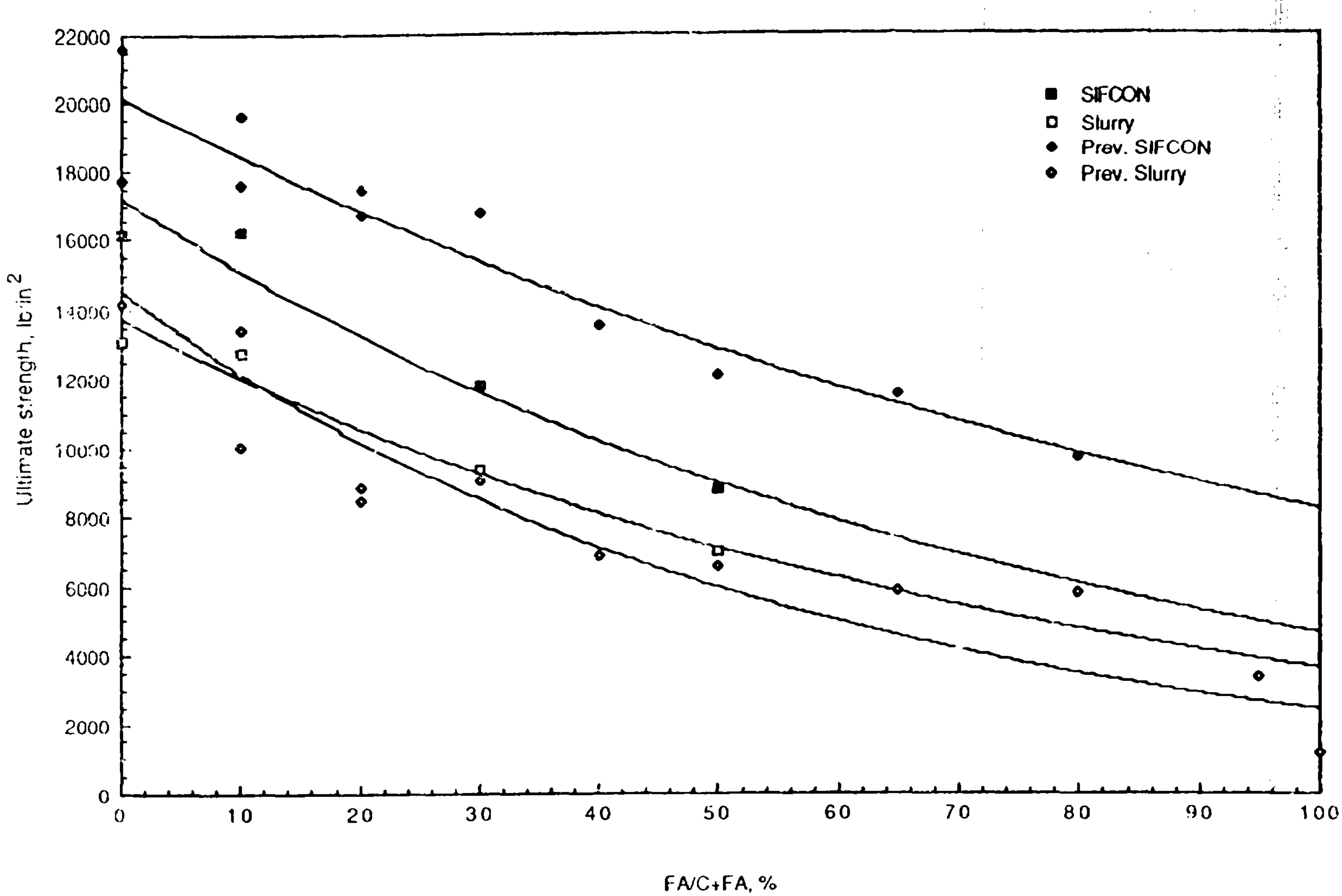


Figure F2. Ultimate compressive strength versus fly/ash cement (W/C+FA=0.30) -- comparison.

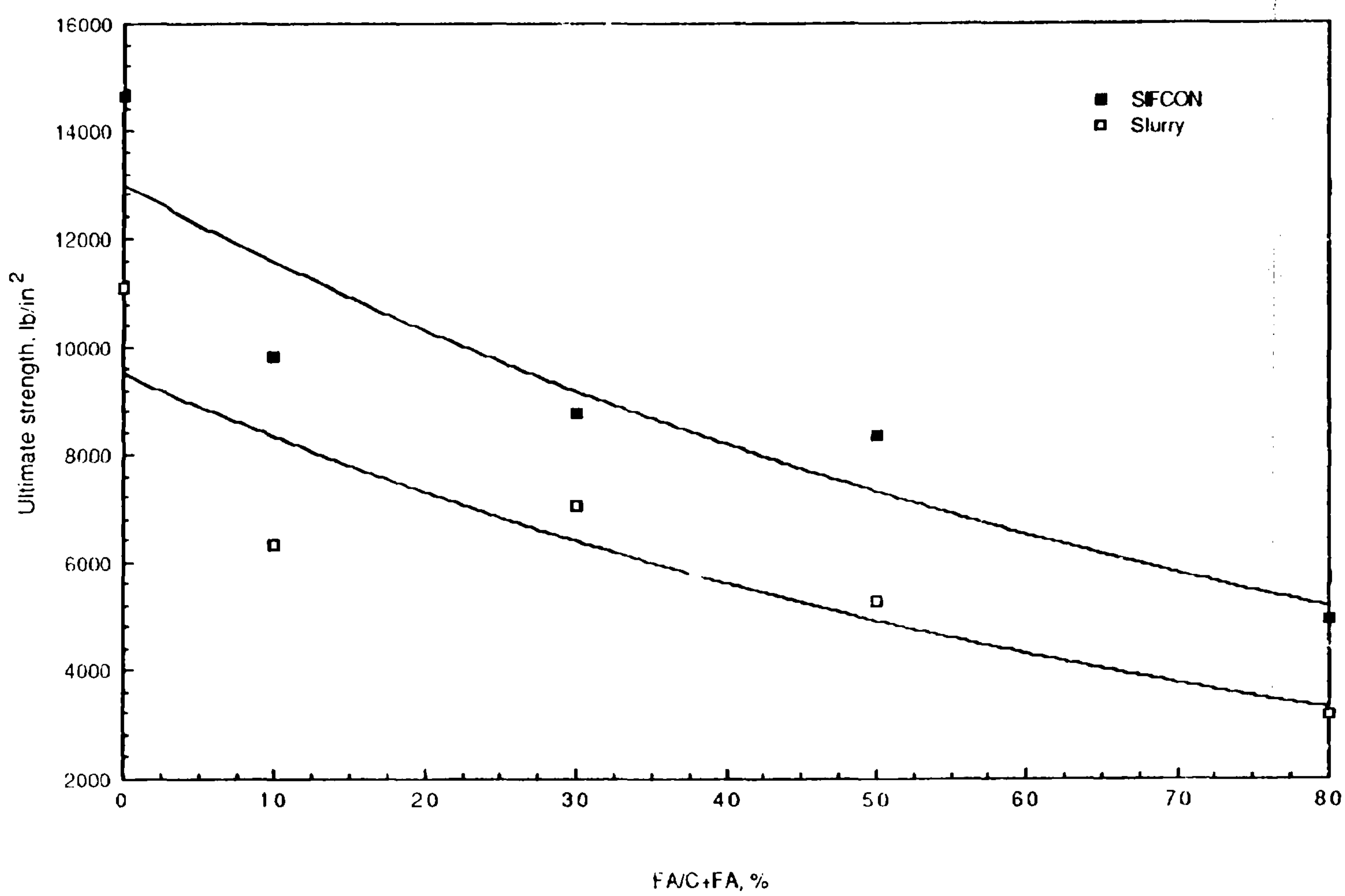


Figure F3. Ultimate compressive strength versus fly ash/cement (W/C+FA-0.40).

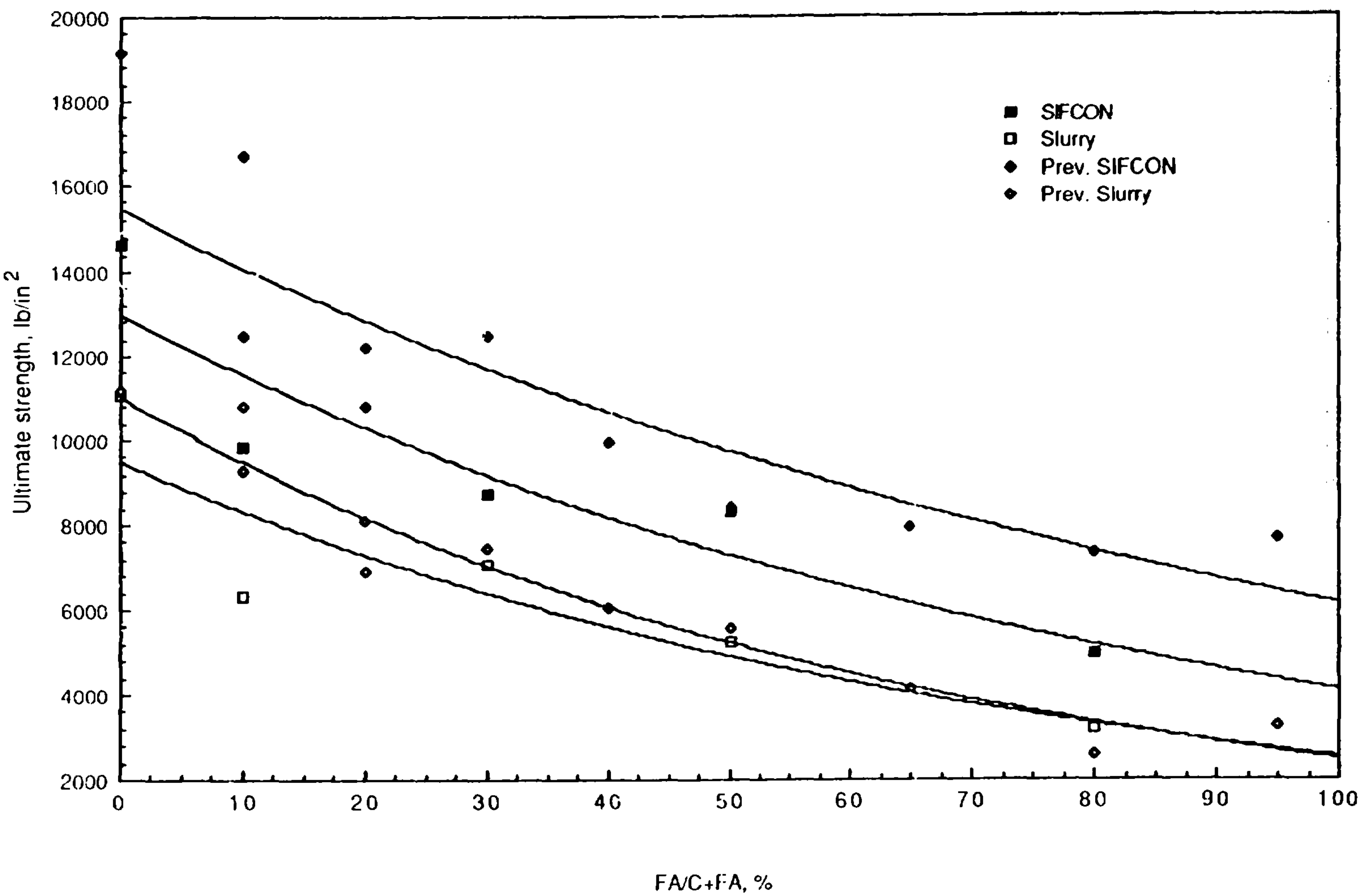


Figure F4. Ultimate compressive strength versus fly ash/cement (W/C+FA=0.40) -- comparison.

APPENDIX G
STUDY GROUP 3: FIBER-TYPE RELATIONSHIPS

This appendix presents additional graphical relationships (not contained in the body of the report) of selected compression and flexure strength parameters for Study Group 3 (Figs. G1-G2).

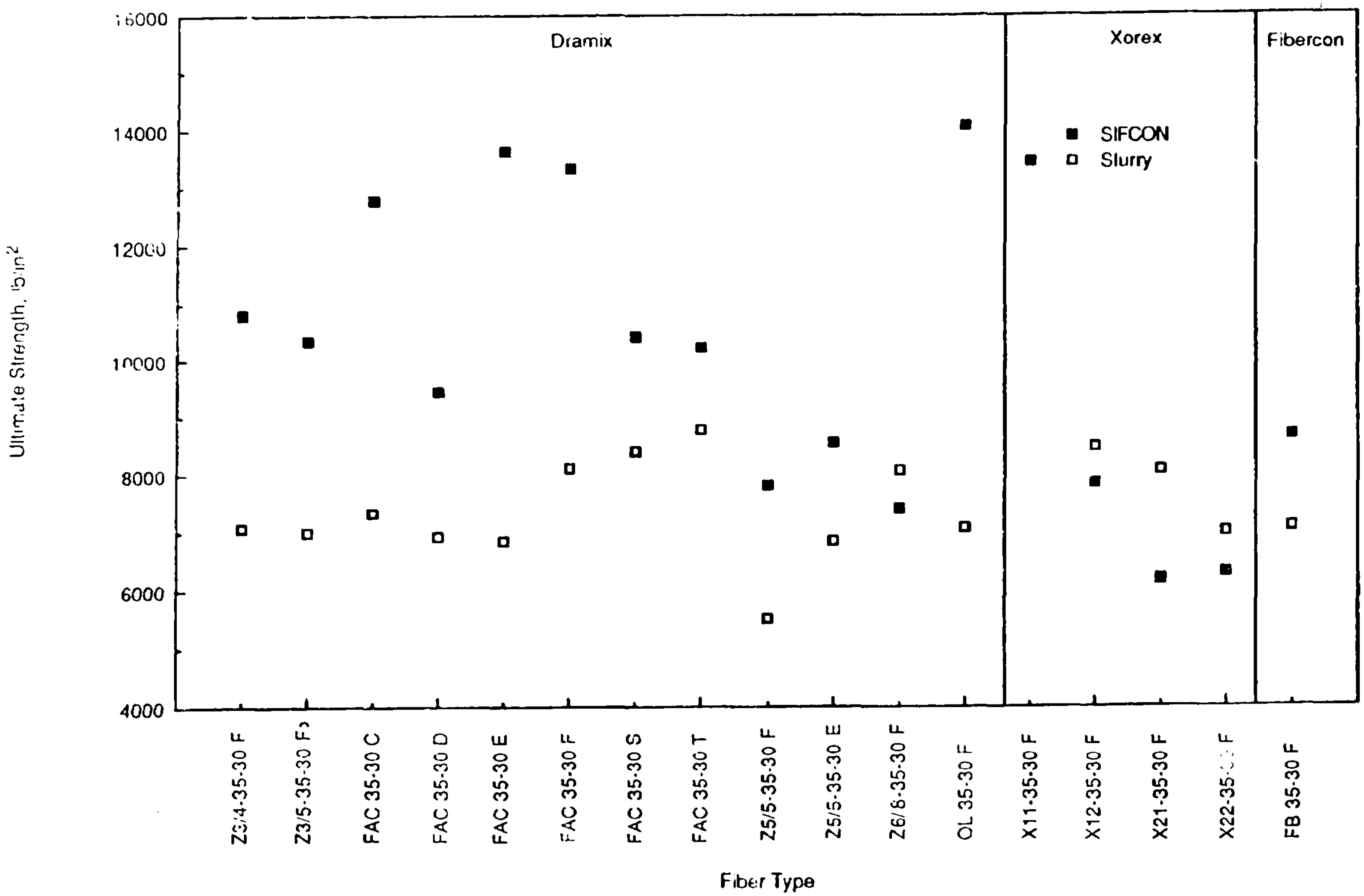


Figure G1. Ultimate Compressive Strength versus Fiber Type.

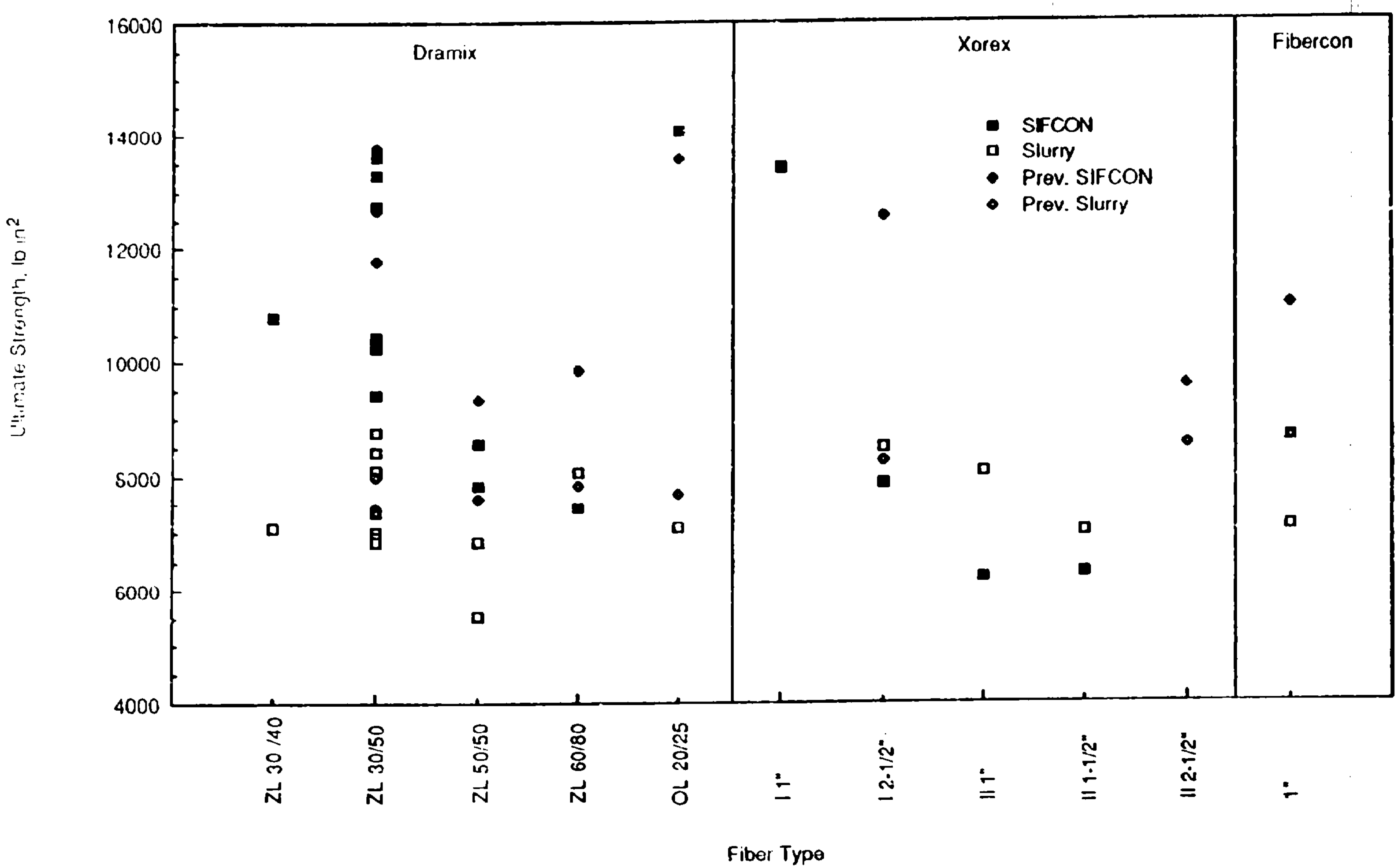


Figure G2. Ultimate Compressive Strength versus Fiber Type - Comparison.

APPENDIX H

STUDY GROUP 4: SAND RELATIONSHIPS

This appendix presents additional graphical relationships (not contained in the body of the report) of selected compression and flexure strength parameters for Study Group 4 (Figs. H1-H4).

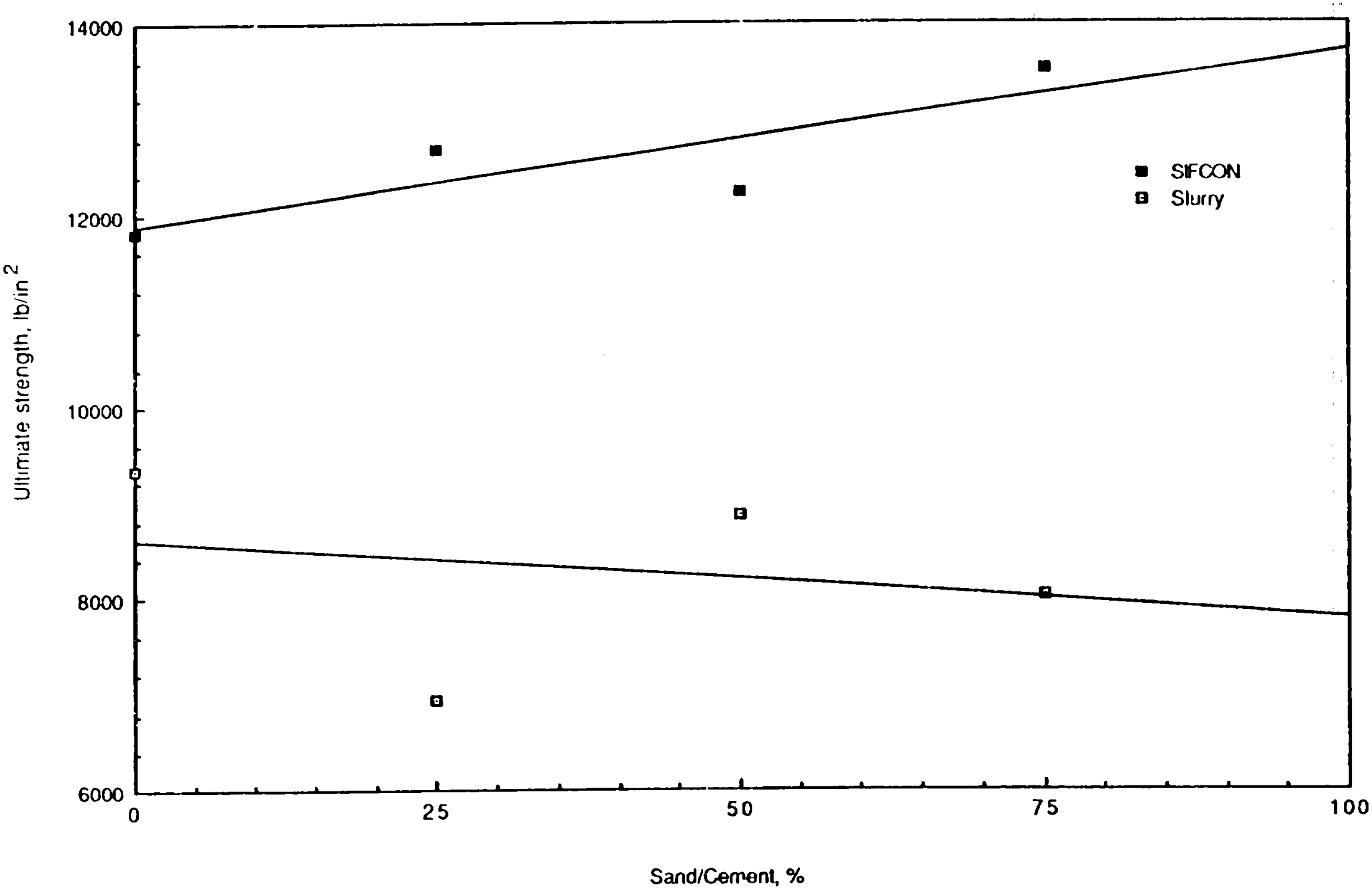


Figure H1. Ultimate compressive strength versus brick sand (W/C + FA = 0.30).

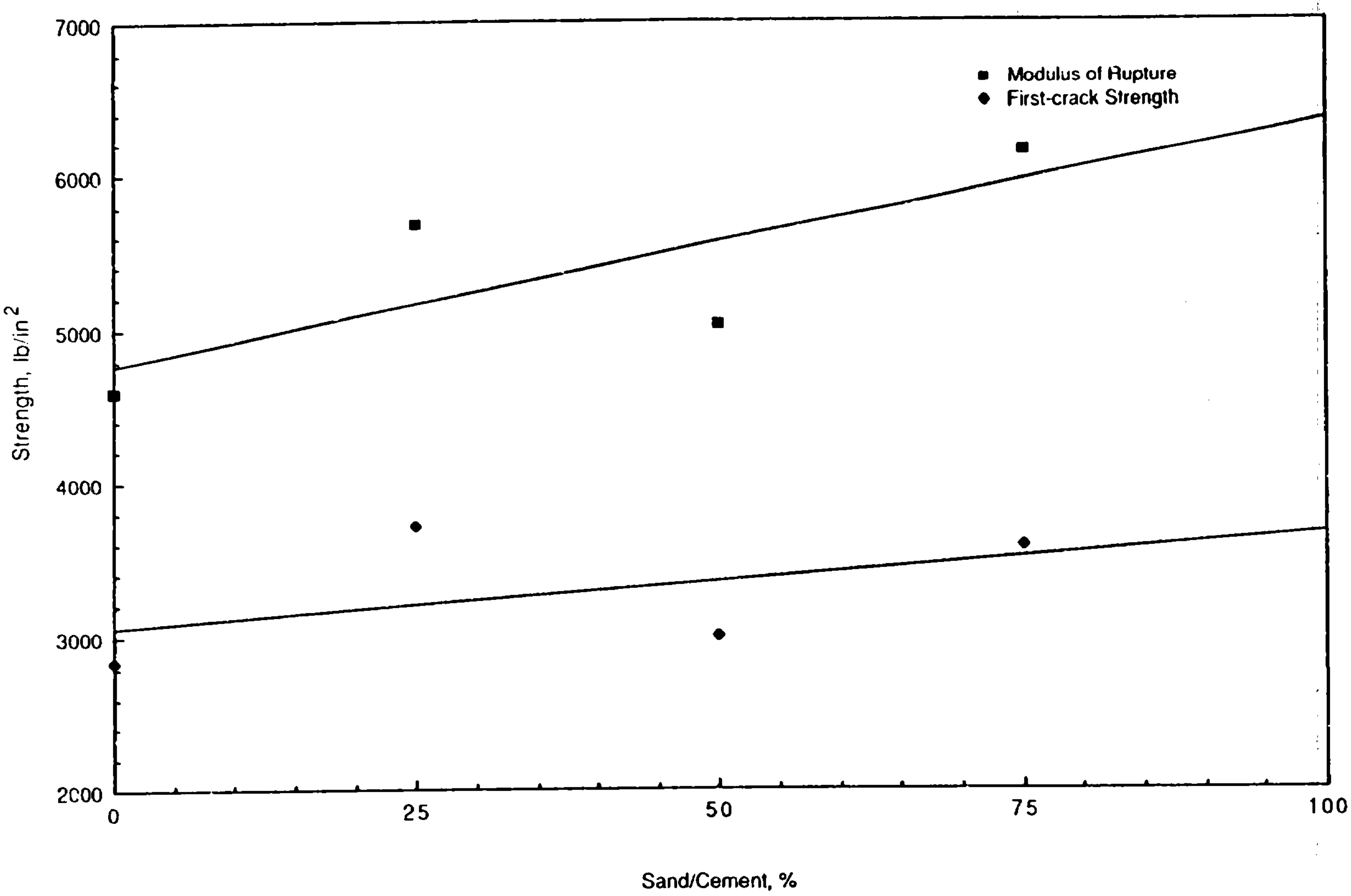


Figure H2. Modulus of rupture and first-crack strength versus brick sand (W/C+FA=0.30).

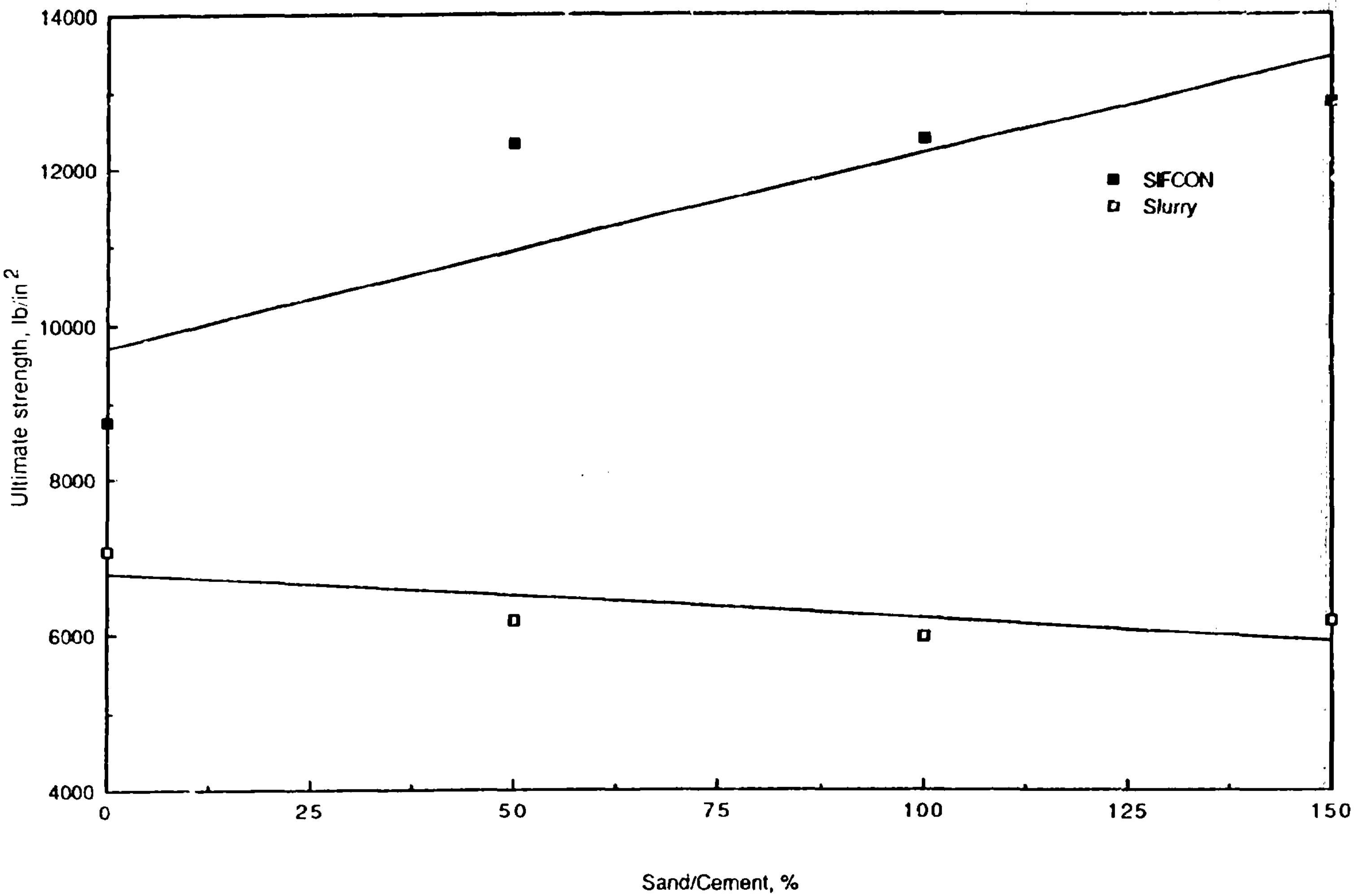


Figure H3. Ultimate compressive strength versus brick sand (W/C + FA = 0.40).

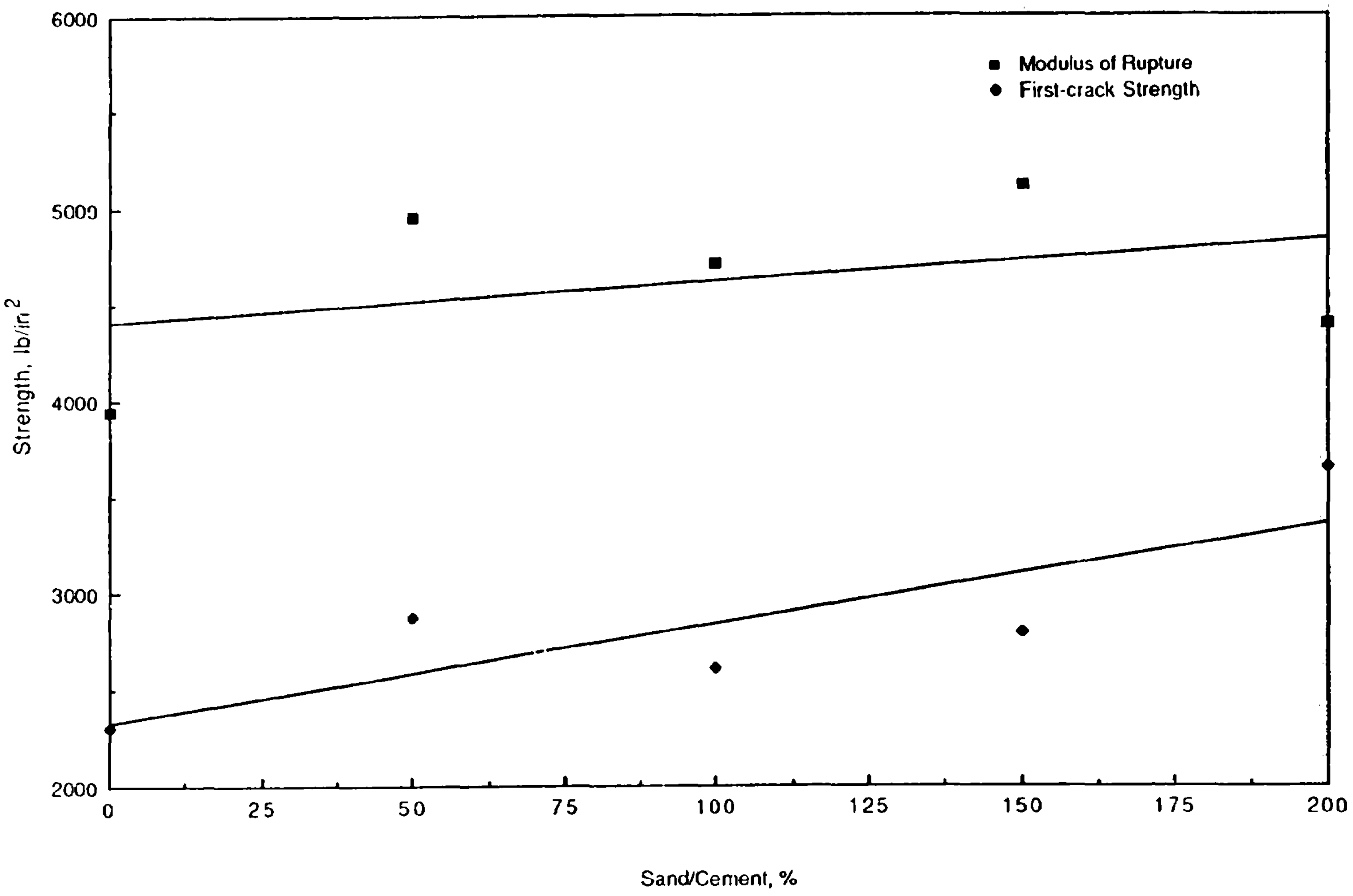


Figure H4. Modulus of rupture and first-crack strength versus brick sand (W/C + FA = 0.40).

APPENDIX I

STUDY GROUP 6 RELATIONSHIPS

This appendix presents additional graphical relationships (not contained in the body of the report) of selected flexure parameters for Study Group 6 (Figs. I1 and I2).

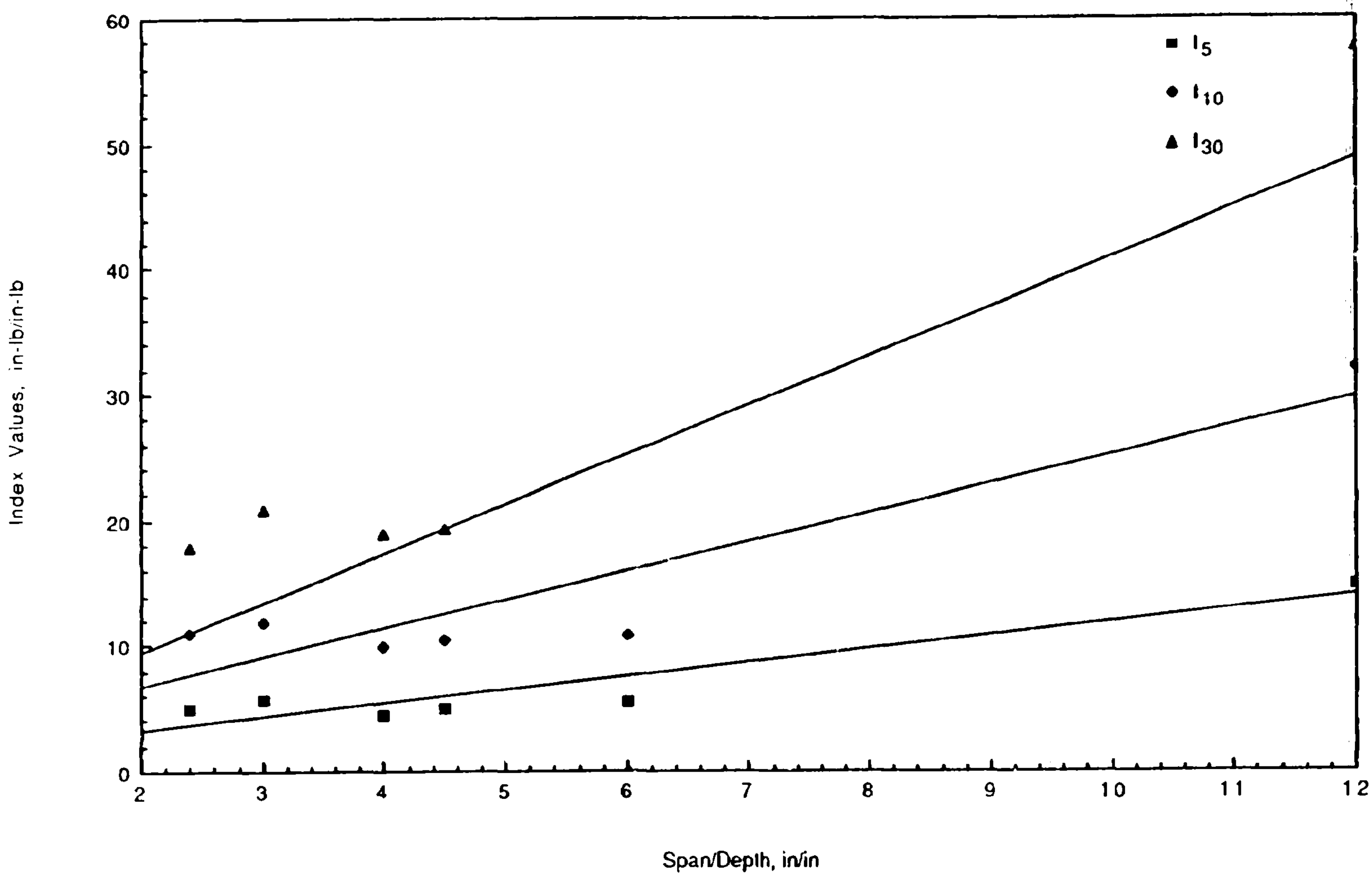


Figure I1. I_5, I_{10}, and I_{30} indexes versus span/depth ratio.

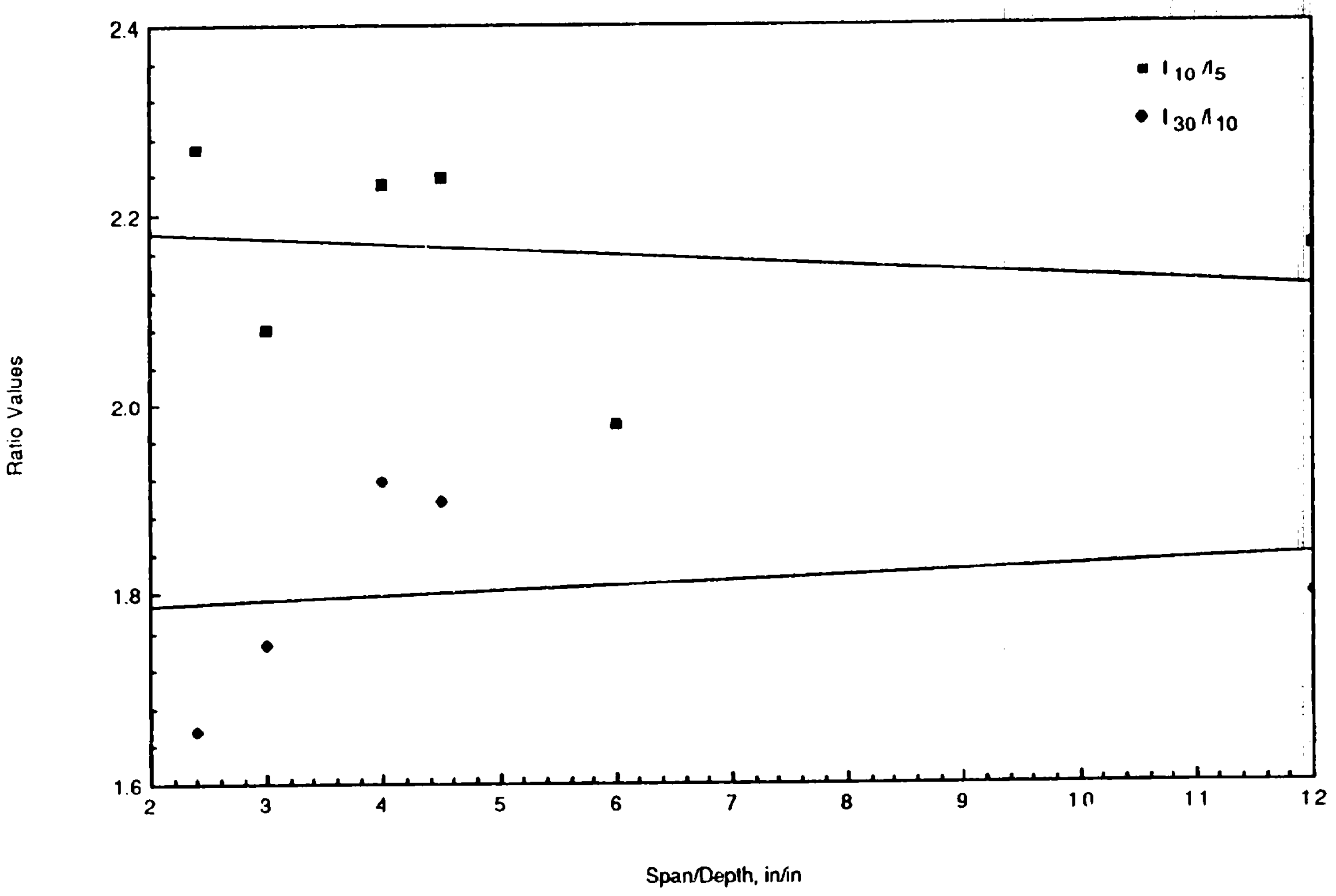


Figure I2. I_{10}/I_5 and I_{30}/I_{10} ratios versus span/depth ratio.

APPENDIX J

PROGRAM QUALITY CONTROL TABLES

This appendix presents tabulated data documenting the program quality control that are not contained in the body of the report. Table J1 lists all the mixes according to the chronological order in which they were molded. The table shows the time of day that mixing began, the TCW room temperature prior to mixing, and temperature of each mix after 7 min of the mixing process (T = 7). Table J2 presents the environment control of the TCW room and mixing ingredients before mixing and mix temperature after 7 min for each of the study groups. Averages as well as minimum and maximum values are given. Table J3 presents dimensional control of the SIFCON test specimens. Again, averages, maximums, and minimums are given for each group. Table J4 presents similar dimension data for slurry cubes. Table J5 presents various sand material properties. The 30-day SIFCON and slurry and 7-day slurry results are presented along with ranges and averages. Table 2 presents a summary of all ultimate strength test results of all identical mixes.

TABLE J1. MIX CHRONOLOGY AND TEMPERATURES

Mix identification code	Date molded, 1986	Start time, am	Temperature	
			Ambient, degrees F	Mix, degrees F
S1-35-30	5/7	10:00		79
S2-35-30	5/12	8:00		78
S3-35-30	5/13	8:00		79
S4-35-30	5/14	8:00		77
S5-35-30	5/15	8:00		76
CW 38-30	5/19	8:00	68	77
CW 43-30	5/20	12:00 pm	70	75
CW 28-30	5/20	9:00	70	80
CW 33-30	5/21	9:00	70	76
FAC 30-80 F	5/22	9:00	70	77
FAC 30-50 F	5/22	1:00 pm		80
Z3/4-35-30 F (FB-35-30 F) and (OL-35-30 F)	5/27	9:00	70	78
FAC 30-30 F	5/28	10:00	69	76
FAC 40-0 F	5/29	12:30 pm	70	75
FAC 30-0 F	5/29	9:00	69	76
Z5/5-35-30 F (X11-35-30 F)	6/2	9:00	59	78
Z6/8-35-30 F (X21-35-30 F)	6/9	9:00	69	77
X12-35-30 F	6/10	11:00	70	78
FAC 30-10 F	6/11	12:00 pm	71	76
Z3/5-35-30 F (X22-35-30 F)	6/12	12:00 pm	70	77
S 75-30-30 F	7/14	9:00		71
S 25-30-30 F	7/14	12:00 pm		76
S 50-30-30 F	7/15	10:00	70	71
S 100-40-30 F	7/16	11:00	71	70
S 200-40-30 F	7/16	9:00	70	71
S 150-40-30 F	7/17	8:00		71
FAC 35-30 T	7/21	9:30	70	71
FAC 40-50 F	7/22	10:00	70	71
S 50-40-30 F	7/23	10:00	70	71
FAC 40-80 F	7/23	9:00	70	76
FAC 35-30 F	7/24	9:00	71	71
FAC 35-30 C	7/28	9:30	68	69
FAC 40-30 F	7/29	2:30 pm	76	76
FAC 40-10 F	7/30	9:00	70	71
FAC 35-30 S	8/4	10:30		77
FAC 35-30 D	8/6			75
FAC 35-30 E (Z5/5-35-30 E)	9/8	9:00		71
Minimum		8:00	68	69
Maximum		*1:00:00 PM	*71	80
Average		9:43	69.8	75.0
* FAC 40-30 F		2:30 pm	76	

TABLE J2. ENVIRONMENT CONTROL SUMMARY

Study Group 1--Water / cement + fly ash

	Wet room temperature, degrees F
Minimum	68
Maximum	76
Average	70.2

Ingredient temperatures			
Cement, degrees F	Fly ash, degrees F	Water, degrees F	Mix, degrees F
68	65	63	69
76	78	74	80
69.9	70.0	68.7	74.7

Study Group 2--Fly ash / cement

	Wet room temperature, degrees F	Ingredient temperatures			
		Cement, degrees F	Fly ash, degrees F	Water, degrees F	Mix, degrees F
Subgroup 2a (W/C+FA = 0.30)					
Minimum	69	69	68	68	76
Maximum	71	71	70	69	80
Average	69.8	69.6	69.0	68.8	77.0
Subgroup 2b (W/C+FA = 0.35)					
Minimum	68	68	65	63	69
Maximum	71	71	71	69	77
Average	69.8	69.3	68.6	67.0	73.0
Subgroup 2c (W/C+FA = 0.40)					
Minimum	70	69	70	69	71
Maximum	76	76	78	74	76
Average	71.2	71.3	72.7	70.3	73.8
Subgroups 2a through 2c combined					
Minimum	68	68	65	63	69
Maximum	76	76	78	74	80
Average	70.3	69.9	69.9	68.7	74.4

Study Group 3--Fiber types

	Wet room temperature, degrees F
Minimum	68
Maximum	71
Average	69.6

Ingredient temperatures			
Cement, degrees F	Fly ash, degrees F	Water, degrees F	Mix, degrees F
68	65	63	69
71	71	70	78
69.4	69.2	68.0	74.5

TABLE J2. CONCLUDED

Study Group 4--Sand

	Wet room temperature, degrees F		Ingredient temperatures: Cement, degrees F	Fly ash, degrees F	Water, degrees F	Mix, degrees F
Subgroup 4a (sand types)						
Minimum	68		68	65	63	69
Maximum	71		75	75	74	79
Average	69.8		71.0	70.7	69.8	75.0
Subgroup 4b (W/C+FA = 0.30)						
Minimum	69		69	69	69	71
Maximum	70		73	73	72	76
Average	69.5		70.3	70.5	69.8	73.5
Subgroup 4c (W/C+FA = 0.40)						
Minimum	70		71	71	70	70
Maximum	76		76	78	74	76
Average	71.8		73.3	73.7	71.7	71.8
Subgroups 4a through 4c combined						
Minimum	68		68	65	63	69
Maximum	76		76	78	74	79
Average	70.5		71.3	71.2	70.1	74.0

All Mixes Combined

	Wet room temperature, degrees F	Ingredient temperatures: Cement, degrees F	Fly ash, degrees F	Water, degrees F	Mix, degrees F
Minimum	68	68	65	63	69
Maximum	76	76	78	74	80
Average	70.0	70.4	70.4	69.5	75.0

Note: Study Groups 5 through 9 are not included separately but their values are contained within the study groups that are included.

TABLE J3. SIFCON DIMENSION SUMMARY

Study Group 1–Water / cement + fly ash

	Core specimens			Beam specimens		
52 cores 43 beams	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
Minimum	2.720	4.852	1.758	3.890	3.890	0.945
Maximum	2.760	* 5.920	* 2.172	4.152	4.152	1.040
Average	2.736	5.469	1.999	4.030	4.030	1.002
* FAC 35-30 D		6.305	2.307			

Study Group 2–Fly ash / cement

	Core specimens			Beam specimens		
	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
16 cores	Subgroup 2a (W/C+FA = 0.30)					16 beams
Minimum	2.730	5.234	1.911	* 3.945	3.944	0.970
Maximum	2.771	5.721	2.073	4.086	* 4.153	* 1.032
Average	2.750	5.468	1.989	4.030	4.027	0.997
* FAC 30-50 F				3.420	4.267	1.248
28 cores	Subgroup 2b (W/C+FA = 0.35)					15 beams
Minimum	2.725	4.852	1.758	3.920	3.948	0.970
Maximum	2.760	* 5.920	* 2.172	4.100	4.135	1.040
Average	2.736	5.454	1.993	4.023	4.049	1.007
* FAC 35-30 D		6.305	2.307			
20 cores	Subgroup 2c (W/C+FA = 0.40)					23 beams
Minimum	2.700	4.930	1.826	3.935	3.895	0.974
Maximum	2.775	5.804	2.112	4.131	4.179	1.043
Average	2.738	5.362	1.958	4.044	4.055	1.003
64 cores	Subgroups 2a through 2c combined					54 beams
Minimum	2.700	4.852	1.758	3.920	3.895	0.970
Maximum	2.775	5.920	2.172	4.131	4.179	1.043
Average	2.740	5.427	1.980	4.034	4.045	1.002

Study Group 3–Fiber types

	Core specimens			Beam specimens		
63 cores 57 beams	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
Minimum	2.711	** 4.852	** 1.758	3.900	3.735	0.942
Maximum	2.779	* 5.920	* 2.172	4.270	4.249	1.059
Average	2.740	5.393	1.968	4.037	4.063	1.007
* FAC 35-30 D		6.305	2.307			
** X22-35-30 F		4.610	1.691			
X11-35-30 F	Rectangular shapes instead of cores					
	Large beams					20 beams
Minimum				5.650	5.356	0.896
Maximum				6.000	5.775	1.061
Average				5.843	5.592	0.962

TABLE J3. CONTINUED

Study Group 4–Sand

	Core specimens			Beam specimens		
	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
16 cores	Subgroup 4b (W/C+FA = 0.30)					19 beams
Minimum	2.720	5.539	2.007	3.952	3.938	0.953
Maximum	2.760	6.005	2.196	4.132	4.196	1.062
Average	2.735	5.718	2.091	4.041	4.063	1.005
16 cores	Subgroup 4c (W/C+FA = 0.40)					17 beams
Minimum	2.700	5.100	1.870	3.935	3.895	0.967
Maximum	2.744	5.940	2.180	4.109	4 155	1.028
Average	2.724	5.354	1.366	4.050	4.032	0.996
32 cores	Subgroups 4b through 4c combined					36 beams
Minimum	2.700	5.100	1.870	3.935	3.895	0.953
Maximum	2.760	6.005	2.196	4.132	4.196	1.062
Average	2.729	5.536	2.028	4.045	4.048	1.001

Study Group 5–Composite Beams

	Core specimens			Beam specimens		
8 cores 34 beams	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
Minimum	2.725	5.503	2.004	3.662	3.849	0.944
Maximum	2.746	5.920	2.172	4.100	4.295	1.103
Average	2.736	5.605	2.049	4.004	4.016	1.003

Study Group 6–Variable Depth Beams

	Core specimens			Beam specimens		
	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
	FAC 35-30 D (1")					5 beams
Minimum				3.946	0.959	0.236
Maximum				4.087	1.091	0.269
Average				4.031	1.002	0.248
	FAC 35-30 D (2")					5 beams
Minimum				3.958	1.952	0.485
Maximum				4.168	2.072	0.505
Average				4.056	2.008	0.495
	FAC 35-30 D (3")					4 beams
Minimum				3.968	3.145	0.762
Maximum				4.125	3.204	0.807
Average				4.043	3.177	0.786
4 cores	FAC 35-30 D (4")					5 beams
Minimum	2.733	5.948	2.176	3.961	4.037	0.997
Maximum	2.733	6.305	2.307	4.078	4.115	1.039
Average	2.733	6.125	2.241	4.027	4.080	1.013

TABLE J3. CONCLUDED

Study Group 6–Continued

FAC 35-30 D (4" long)				5 beams
Minimum		3.769	4.117	1.030
Maximum		3.998	4.275	1.122
Average		3.907	4.193	1.074
FAC 35-30 D (5")				**5 beams**
Minimum		3.951	5.087	1.258
Maximum		4.082	5.187	1.303
Average		4.023	5.144	1.279

Study Group 7–Edge effects

16 cores	Core specimens		
	Diameter, in	Height, in	Height/diam, ratio
Minimum	2.760	4.584	1.661
Maximum	2.767	5.421	1.959
Average	2.764	5.065	1.835

Study Group 8–Shear Tests

8 cores 17 beams	Core specimens			Beam specimens		
	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
Minimum	2.725	5.580	2.048	3.910	5.094	1.248
Maximum	2.735	5.775	2.119	4.090	5.275	1.323
Average	2.730	5.703	2.089	4.032	5.145	1.276
Minimum				3.920	3.992	0.980
Maximum			5 beams	4.090	4.075	1.026
Average				4.023	4.030	1.002

Study Group 9–Tension Tests

4 cores 24 tension sp.	Core specimens			Tension specimens	
	Diameter, in	Height, in	Height/diam, ratio	Thickness, in	Minimum width, in
Minimum	2.725	5.580	2.048	1.910	1.960
Maximum	2.725	5.775	2.119	2.165	2.170
Average	2.725	5.691	2.089	2.021	2.047

All Mixes Combined (typical specimens)

147 cores 174 beams	Core specimens			Beam specimens		
	Diameter, in	Height, in	Height/diam, ratio	Width, in	Heigth, in	Height/Width, ratio
Minimum	2.700	4.584	1.661	3.662	3.735	0.942
Maximum	2.779	6.005	2.196	4.270	4.295	1.103
Average	2.738	5.440	1.987	4.031	4.049	1.004

TABLE J4. SLURRY DIMENSION SUMMARY

Study Group 1–Water / cement + fly ash

	7-day Height, in	30-day Heigth, in
Cubes	39	36
Minimum	2.868	2.805
Maximum	3.198	3.156
Average	3.063	3.050

Study Group 2–Fly ash / cement

Subgroup 2a

	7-day Height, in	30-day Heigth, in
Cubes	14	15
Minimum	3.003	3.004
Maximum	3.162	3.162
Average	3.073	3.084

Subgroup 2b

	7-day Height, in	30-day Heigth, in
Cubes	21	19
Minimum	2.868	2.805
Maximum	3.142	3.133
Average	3.055	3.030

Subgroup 2c

	7-day Height, in	30-day Heigth. in
Cubes	15	13
Minimum	2.857	2.846
Maximum	3.139	3.090
Average	3.031	3.023

Subgroups 2a through 2c combined

	7-day Height, in	30-day Heigth, in
Cubes	50	47
Minimum	2.857	2.805
Maximum	3.162	3.162
Average	3.053	3.045

Study Group 3–Fiber types

	7-day Height, in	30-day Heigth, in
Cubes	33	31
Minimum	2.868	2.805
Maximum	3.197	3.199
Average	3.067	3.052

TABLE J4. CONCLUDED

Study Group 4--Sand

Subgroup 4a

	7-day Height, in	30-day Heigth, in
Cubes	14	104
Minimum	3.018	3.000
Maximum	3.128	3.212
Average	3.063	3.105

Subgroup 4b

	7-day Height, in	30-day Heigth, in
Cubes	12	12
Minimum	3.066	3.005
Maximum	3.140	3.120
Average	3.111	3.076

Subgroup 4c

	7-day Height, in	30-day Heigth, in
Cubes	15	14
Minimum	2.990	2.930
Maximum	3.125	3.090
Average	3.075	3.043

Subgroups 4a through 4c combined

	7-day Height, in	30-day Heigth, in
Cubes	41	130
Minimum	2.990	2.930
Maximum	3.140	3.212
Average	3.087	3.095

Study Group 7–Edge effects

	7-day Height, in	30-day Heigth, in
Cubes	3	3
Minimum	3.108	3.114
Maximum	3.133	3.142
Average	3.118	3.128

All Mixes Combined

	7-day Height, in	30-day Heigth, in
Cubes	112	199
Minimum	2.857	2.805
Maximum	3.198	3.212
Average	3.072	3.082

TABLE J5. SAND PROPERTIES

Sieve analysis

Sieve size, no.	Passing sieve, percent				
	Brick sand	Plaster sand	Blasting sand		
			Coarse	Medium	Fine
4	100	100	100		
8	98.9	98.2	99.8	100	100
16	93.4	89.8	12.3	94.2	99.7
20	89.7		10.7	76.6	
30.	84.8	71.7	8.3	48.2	98.0
40	76.6			16.9	86.2
50	52.9	31.1	2.6	5.1	58.5
80				1.0	24.8
100	13.9	7.4			17.7
200	5.3	2.9	1.1	0.7	6.7

Specific gravity

2.58 - 2.60

Absorption

0.8 percent

Note : All data provided by sand supplier.

APPENDIX K

DATA REDUCTION PROCEDURES

This appendix presents a detailed list of the procedures used in the reduction and generation of the report data from the laboratory-generated data.

The acquisition and reduction of test specimen data included within this report was accomplished by the following steps:

1. Acquisition of load-deformation plot for test specimens.
2. Selection of data points from test specimen plot.
3. Computation of various slopes on test specimen plot.
4. Adjustment of test specimen plot for testing machine zeroing.
5. Computation various test data for test specimen, from selected points.
6. Computation of average plot of test specimens.
7. Plotting of test specimen plots and their average.
8. Plotting of computed test data for various mix designs.
9. Production of data base for test specimen.

DATA ACQUISITION

A basic program called "Data Acquisition 1.0" (Ref. K-1) was developed for use on a Macintosh 512K personal computer. This program interfaces the Macintosh personal computer to a Tinus Olsen 400K Universal Testing Machine (UTM). The UTM, located at the University of New Mexico Civil Engineering Structural Testing Laboratory, was used for testing SIFCON test specimens. "Data Acquisition 1.0" is a program which was written in Microsoft Basic (Ref. K-2). This program controls an analog/digital converter which allows direct acquisition of load-deformation data from the load and deflection cells of the UTM. This information was stored directly to a file on computer diskette. The program converts UTM voltage into either load/deformation or stress/strain x-y data pairs depending on what type of test was performed on the test specimen. The file for each test specimen also contained information regarding test specimen dimensions, test date, and the name of the technician who operated the testing machine.

K-1. Moore, T. A., "Data Acquisition 1.0," Computer Software Program, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, New Mexico, March 1987.

K-2. Microsoft Corporation, "Microsoft Basic 2.0," Interpreter Software For Apple Macintosh, Redmond, Washington, 1984.

Test specimen plot files, which were not recorded by "Data Acquisition 1.0" due to loss of power during testing, or files which had large discrepancies from the load/deformation plots produced by the plotter, were hand digitized. The load/deformation plots for these test specimens were digitized using a basic program called "Plot 05 Digitizer" (Ref. K-3) which was developed for and used on a Tektronix 4052 Graphics System. Files of x-y data pairs were created and stored on magnetic tape. These data were converted to stress/strain pairs or left as load-deformation pairs. The digitized data files were transferred to an HP 9000 Computer System where they were later transferred to Macintosh computer diskettes. The files were saved with the same format as "Data Acquisition 1.0" files.

DATA REDUCTION

Data Point Selection -- A basic program called "Data Reduction 1.0" (Ref. K-4) was developed to plot test specimen x-y data on the Macintosh screen so that specific points could be chosen from an x-y plot for each test specimen. These plots were stress versus strain, for compression and tension tests; and load versus deformation, for flexure and shear tests. The points selected were either stresses and strains, or loads and deformations at Points A, B, C, and D, (refer to Figs. 18 through 21). The x-y data pairs and other test data acquired were saved in an Excel (Ref. K-5) database file for each test specimen.

Slope Computation--The slope (modulus of elasticity for stress versus strain) between the origin and Point A for all tests, and between Points B and C for the stress versus strain plots, was calculated using "Data Reduction 1.0."

The slope between specific points was determined using the method of least squares procedure for determining the equation of a straight line from data between specific points.

K-3. Emery, R., "Plot 05 Digitizer," Computer Software Program, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, New Mexico, June 1984.

K-4. Moore, T. A., "Data Reduction 1.0," Computer Software Program, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, New Mexico, March 1987.

K-5. Microsoft Corporation, "Microsoft Excel 1.03," Complete Spreadsheet And Database Software With Graphics For Apple Macintosh, Redmond, Washington, 1986.

The equation of a straight line is:

$$y = mx + b$$

where m = slope of the line and b = the y-intercept. The slope m and y-intercept were calculated using the equations:

$$\text{slope} = \frac{\Sigma x \, \Sigma y - n \, \Sigma(x*y)}{(\Sigma x)^2 - n\Sigma(x^2)} \quad ; \quad \text{y-intercept} = \frac{\Sigma y - \text{slope} \, (\Sigma x)}{n}$$

where n = number of data points used to determine the slope. This slope value was stored in the same Excel database file as the specific points that were selected from the test specimen plots. Slope values were obtained for compression, tension, flexure, and shear test specimens.

Testing Machine Adjustment -- The test specimen plot data file was adjusted for testing machine zeroing. The load-versus-deflection curves obtained from the UTM plotter shows a short curved section at the beginning of each curve. This nonlinear portion of the curve was attributed to testing machine adjustment and plotter zeroing techniques. The x-y data pairs were adjusted for these effects by using the first slope value previously calculated and the point where the nonlinear portion of the curve becomes linear, a new x-axis intercept was determined by the equation:

$$\text{x-intercept} = \frac{-\,(\text{y-intercept})}{\text{slope}}$$

The value of the x-intercept was the distance from the origin of the original data set to the point where the extension of the slope from the y-intercept crosses the x-axis. This value was subtracted from each of the x-values of the x-y data pairs.

TEST DATA COMPUTATIONS

Computations of Compression and Tension Results -- The load/deformation data obtained from compression and tension tests was converted to stress/strain data by the program "Data Acquisition 1.0" or "Plot 05 Digitizer" using the following equations:

$$\text{stress} = \frac{P}{A} \ (\text{lb/in}^2) \ ; \quad \text{strain} = \frac{\Delta L}{L} \ (\text{in/in})$$

where P = load applied , A = test specimen cross-sectional area, ΔL = change in length, and L = test specimen overall length.

Computation of Flexure and Shear Results -- The load/deflection data obtained from flexure and shear tests was saved directly to diskette by "Data Acquisition 1.0."

The flexure and shear, strength and toughness data contained in Tables D1 through D7 were determined using Reference K-6, which includes the following equations (refer to Fig. 19):

$$\text{1st-crack strength} = \frac{\text{load}_A(l)}{bd2} \ (\text{lbs/in2})$$

$$\text{1st-crack deflection} \ (\Delta_A) = \text{defl}_A \ (\text{in})$$

$$\text{ultimate strength} = \frac{\text{load}_B(l)}{bd2} \ (\text{lbs/in2})$$

$$\text{ultimate deflection} = \text{defl}_B \ (\text{in})$$

K-6 Amercian Society for Testing and Materials, "Flexure Toughness and First Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)," Standard ASTM C1018-85, Philadelphia, Pennsylvania, 1985.

$$1\text{st crack toughness}(T_1) = \frac{1}{2}\, load_A \Delta_A$$

$$\text{toughness index } I_5 = \frac{(3\Delta_A \text{ area})}{T_1}$$

$$\text{toughness index } I_{10} = \frac{(5.5\Delta_A \text{ area})}{T_1}$$

$$\text{toughness index } I_{30} = \frac{(15.5\Delta_A \text{ area})}{T_1}$$

where b = beam width, d = beam depth, and l = tested span length of the beam, and the letter subscript indicates the selected point; area under the load deflection curve was determined using Simpson's rule for determination of irregularly shaped areas.

Shear test results shown in Table D7 are ultimate load and deflection at Point A, as shown in Figure 20.

Test Value Variation -- The percent variation in the test values was calculated using the equation:

$$\text{variation} = \frac{(\text{max. value} - \text{min. value})}{(\text{max. value})} \times 100$$

where the values were average test values.

Average Plot Computation -- Using "Data Reduction 1.0" selected test specimen files for each mix design were averaged together. An algorithm which uses the running average technique was developed and used to create a file which contained average x-y data

for the test specimens of each mix design. This file was plotted along with the selected test specimen's data for the mix design, as shown in Appendix C.

Data Plot Computations -- A plotting macro called "Flex Plot 1.0" (Ref. K-7) was developed for Excel (Ref. K-5), the data base graphics applications for the Macintosh. Files containing plots of test specimen x-y data were created using this macro for each mix design. These plots are shown in Appendix C.

Data Base Production -- Excel chart documents were produced using the data from the databases created by the basic program "Data Reduction 1.0." These plots are shown in Appendix D. The values used to produce these plots were computed test data from the test specimens of each mix design.

The average values which were stored in the Excel data base were generated by averaging the values chosen from each of the selected test specimen plots for each mix design. As an example, for Point D (referring to Figs. 18 through 21), the average value of this point would be the sum of the values picked from the various selected plots divided by the number of values summed.

The averaging technique used in this test series (Flexural Strength) is different than the technique which was used in the previous test series (Compression Strength). As explained above, the average values which are shown in Appendix D consist of the average of all the curves, while the values used in the Compressive Strength test series were values picked from the average curve.

K-7. Moore, T. A., "Flex Plot 1.0" Computer Software Macro, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, New Mexico, March 1987.

APPENDIX L
MISCELLANEOUS INFORMATION

This appendix presents a list of test program general data (Table L1) and sample data sheets used in the tests.

TABLE L1. TEST PROGRAM GENERAL DATA

Personnel	
Research engineer:	Ray Mondragon
Student engineering assistant:	Ted Moore
Lead technician:	Ival Brick
Assistant technician:	Chris Broadway
Test program period	
First mix:	May 7, 1986
Last mix:	September 8, 1986
Last test:	October 8, 1986
Locations	
KAFB Building 20360:	Management, data reduction, report writing
KAFB Building 734:	Mix preparation, coring, cutting, and milling of specimens
Temperature control wet room (within Bldg. 734):	Curing of specimens and storage of mix ingredients, molds, etc.
UNM Civil Engineering Materials Laboratory:	Testing of specimens
Mix data	
Fiber vibration time:	120 ± 5 s plus 30 ± 5 s
Mix vibration time:	2 to 6 min (except as noted)
Batch size:	1.8 ft^3/batch (general)
Mold stripping time:	22 h ± 15 min
Mix ingredients	
Cement:	Ideal - Type I and II
Fly ash:	Front Range Fly Ash - Class C
Water:	KAFB Well No. 2, Facility 26025 tap water
Superplasticizer:	Masterbuilders - 400N
Fiber:	Various (see Table 2)
Sand:	Albuquerque Gravel Products - brick sand, plaster sand, and fine, medium, and coarse blasting sands
Major equipment	
Specimen molding equipment	
Scale:	Pelouze Scale Co. Model 333755, 206-lb capacity
Mortar mixer:	Francis Wagner, electric 6-ft^3 capacity Model 625 PM
Slab molds:	12.5 in x 15 in x 6 in (nominal)
Vibration table:	NMERI design

TABLE L1. CONCLUDED

<u>Major equipment (continued)</u>	
Testing equipment	
Testing machine:	Tinius-Olsen 400,000-lb capacity No. 13727
Electronic extensometer:	Tinius-Olsen 2000 recorder No. 139,000
Deflectometer:	Tinius-Olsen Type D-2 No. 142765
Flow cone:	Humbolt Mfg. Co.
Curing tanks:	2-ft x 2-ft x 6-ft galvanized water tanks
Core drill:	Milwaukee Electric Tool Corp., Cat. No. 4039, 1200/600 r/min
Drill bits:	3-in, diamond-tipped
Cutting machine:	Rayteck 18-in saw, S-18A, No. 000408
Milling machine:	DoAll grinding mill (D-6), No. 3955657
Data reduction equipment	
Tektronix graphics system:	Tektronix 4052 CPU terminal unit Tektronix 4956 graphics tablet
Macintosh XL computer network system:	Macintosh XL personal computer Macintosh 512K personal computer Macintosh 1Mb personal computer Macintosh ImageWriter printer Macintosh LaserWriter printer
HP 9000 computer system:	HP 2392A CTR terminal HP 7935 disk drive HP 7914ST tape drive HP 2563A printer HP 7550A graphics plotter

SIFCON Testing Program

Identification : ______________

Sampling Date : ______________

Check List/Data Sheet

Task	Data: Required	Data: Actual	✓
I. Preparations		Ambient / High / Low (F)	
1. Control room temperature	70 F 2	___ ___ ___	
2. Water temperature	Tank #1	___ ___ ___	
	Tank #2	___ ___ ___	
3. Caulk and oil molds			___
II. Fiber Placement			
1. Hain in fiber consistently	34 lbs. ZL 30/50	______ lbs.	
2. Vibrate fiber	120 sec. 5	______ sec.	
3. Rain in remaining fiber		______ lbs.	
4. Vibrate total	30 sec. 5	______ sec.	
III. Measure Ingredients		Temp.(F) / Weight (lbs.)	
1. Cement	______ lbs.	______ ______	
2. Fly ash	______ lbs.	______ ______	
3. Water	______ lbs.	______ ______	
4. Additive ______	______ lbs.	______ ______	
5. Superplasticizer	______ cc	______ cc	
6. Mix water & superpl.			___
IV. Mix Ingredients			
1. Dampen mixer			___
2. Place 80% water in mixer			___
3. Start mixer	T=-10 sec.		
4. Mix FA, C, & A	T=0	T= :00	
5. Clean & add last water			___
6. Mix until T=6 min.	T=6 min. 5 sec.	T= :06	
7. Flow test & mix temp.		______ sec. ______ F	
8. Let mix set until T=9 min.	T=9 min. 5 sec.	T= :09	
9. Remix for 60 sec.	T=10 min. 5 sec.	T= :10	
V. Mold Samples			
1. Start vibration & pour slurry	Simultaneously		___
2. Vibrate samples	2 to 6 min.	#1 ______ #2 ______	
3. Place in wet room			___
4. Take flow test & temp.	Time (min. 5 sec.)	Time / Temp. / Flow	
	T=30	T= :30 ______	
	T=45	T= :45 ______	
	T=60	T= :00 ______	
	T=90	T= :30 ______	
	T=120	T= :00 ______	
	T=150	T= :30 ______	
	T=180	T= :00 ______	

Notes :

Identification : ______________

	Required		Actual
VI. Specimen Preparation	22hr. 15min.	T= ______ +	______
1. Strip molds			
2. Place specimens in tank #1	B1	(A) (B) (C) (D)	______
3. After 7 days place in tank #2	B2	B4	
4. Prepare specimens	B3	B5	______
5. Measure dimensions			
6. Keep specimens in water until test			

VII. Test Day # ______________ +

Cores	Beams	Cubes	Dates
______	______	______	______

1. Prepare specimens
2. Test specimens

Cores Diam.	Cores Ht.	Cores Load	Time	Beams Width	Beams Ht.	Beams Load		Cubes Ht.	Cubes Load
							a		
							b		
							c		

VIII. 30 Day Test ______________ +

Cores	Beams	Cubes	Dates
______	______	______	______

1. Prepare specimens
2. Test specimens

A					B1				d		
B					B2				e		
C					R3				f		
D					J4						
					B5						

Notes: